AMEagle

Volume 21 FEBRUARY, 1937 Number 2

BULLETIN
of the
American Association of Petroleum Geologists

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BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 608 WRIGHT BUILDING, TULSA, OKLAHOMA

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 608 Wright Building, Tulsa, Oklahoma, Post Office Box 1852. Cable address, AAPGEOL.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

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German agent: Max Weg, Königstrasse 3, Leipzig, Germany.

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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 1852

TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

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(Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.)

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Articles for March *Bulletin*

BULLETIN ADVERTISERS

PROFESSIONAL CARDS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

Volume 21 Number 2

BULLETIN
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

FEBRUARY, 1937

THE ECONOMIC STRUCTURE OF THE AMERICAN PETROLEUM INDUSTRY[1]

JOSEPH E. POGUE[2]
New York, N.Y.

ABSTRACT

This paper presents an analysis of the economic forces that govern the functioning of the American petroleum industry, and outlines the changes that are taking place in their incidence. After a general introduction, the study deals with the five structural components of the industry—exploration, production, transportation, refining, and marketing—then takes up a number of special aspects of the business, and concludes with emphasis on the evolving aspects of the new structure introduced by the institutionalization of proration. The field of exploration is accorded rank as a separate economic function, coördinate in importance with production, and it is shown that sustained discovery is dependent upon multiple competitive effort despite revolutionary advances in the technique of search. Production, long dominated by the principle of capture, is described as undergoing fundamental modification under the impact of a control mechanism, itself in course of change. Proration is analyzed as a conservation measure and as a device for balancing supply and demand, tending to nullify the adverse effects of the rule of capture; with further developments to this end suggested. The specialized nature of transportation is described and its integrative aspects noted. The refining function is viewed with special regard to the powerful influence of changing technology. The field of distribution is examined as the terminal expression of economic pressures and an incipient schism of the retail function is noted. Throughout, the desideratum of equilibrium is emphasized and employed as a criterion in judging functional effectiveness. Finally it is pointed out that the oil business is the first great American industry to develop a new method of conducting its business. Its experiment with a new operating form has made some headway toward the practical solution of a complicated problem of unique character.

INTRODUCTION

The petroleum industry is marked by two features which, while not lacking in other industries, are nevertheless not so thoroughly de-

[1] Read before the Third World Power Conference at Washington, D.C., September, 1936. Reprinted by permission of the writer and the Third World Power Conference, O. C. Merrill, director.

[2] Vice-president, The Chase National Bank; formerly consulting engineer.

veloped elsewhere. These special characteristics are: a vertical structure that involves an integration of activities from the raw material to the ultimate consumer; and the presence of an essential function, discovery, that must operate far in advance of the production of the raw material. The petroleum industry, therefore, rests upon the coördinated operation of five sequential fields of activity—search, production, transportation, manufacturing, and distribution—each unique and specialized, and all directed and adjusted by the economic forces that surround this complex of activities. The petroleum industry in the United States is also distinguished from this field of enterprise in most other countries by the prevalence of oil fields of subdivided ownership. Under the impact of the rule of capture, this circumstance gives rise to an uneconomic phase of interlease competition which constitutes a handicap that the industry has succeeded in mitigating through the development of unit operation and proration, but has not yet eradicated. Functional integration, the necessities of continuing discovery, and the influences set up by the rule of capture, will go far toward providing the basis for an economic analysis of this large and important component of the national economy.

The purpose of this paper is to attempt to set forth the economic forces that activate the American petroleum industry, to appraise their effectiveness and limitations, and to outline the functional changes that are taking place in this field of enterprise. To this end we shall strive to visualize the economic structure of the industry in both space and time and thus view the problem in its dynamic aspect.

GENERAL DESCRIPTION OF THE INDUSTRY

The petroleum industry is based upon the utilization of a natural resource, petroleum, and also draws upon the heavier components of a related hydrocarbon, natural gas. Petroleum is widely distributed both geographically and geologically, but is confined to sedimentary rocks and favors the geologically younger rocks of the earth. The individual deposits of oil are widely scattered, usually small in extent, and are hard to find. A scarcity element is, therefore, often involved. According to Pratt:[3]

> Of the proven reserves of oil in the world today, amounting to somewhat less than 25 billions of barrels, approximately one-half are within the United States. The enterprise of winning oil from the earth is essentially a geological

[3] Wallace Pratt, "Oil Production—Its Development and Stabilization." Address before Natural Resources Round Table, U. S. Chamber of Commerce, Washington, May 1, 1935.

venture. Oil fields are invariably creatures of the shore processes of former seas. Just as coal results from the metamorphosis of the organic matter of former plants, buried in the fresh water of inland swamps, so oil forms from the remains of marine life that are entombed in the briny muds of shallow-sea floors.

The American petroleum industry is large in size and occupies an important position in the national economy. While accurate figures are not available, a capital investment of the order of magnitude of 12 billion dollars is estimated to be involved. According to the American Petroleum Institute,[4] the oil business employs directly about 1,000,000 people, and in 1934, its pay roll was nearly $1,250,000,000 (Fig. 1). "It has been notably free from labor troubles, due to liberal policies in dealing with a large and exceptionally high-grade personnel."[4] Because of its high degree of mechanization, the ratio of capital to number of employees is large, the indicated relationship being $12,000 of investment for each worker. This ratio is much larger in production, transportation, and refining than in the field of distribution where 72 per cent of the total personnel is concentrated. This relationship alone accords distribution a different status from the rest of the industry and binds it thereto with a weaker link than is found uniting the other functions.

The growth of the American petroleum industry has been very rapid (Figs. 2 and 3) and the growth factor has exerted a profound effect upon the economic structure of the business. Although petroleum was first produced commercially in the United States in 1859, the industry has only assumed quantitative importance in the past 25 years, paralleling the rise of automotive transportation. The demands of new and expanding markets, in conjunction with the potentialities of commodity and energy values in liquid form, formed the stimulus for the creation *de novo* of a specialized enterprise, which, finding few materials ready at hand in the general economy, proceeded to construct its full range of activities in integrated form. To a notable degree the petroleum industry is organized along vertical, self-contained lines. The same set of circumstances determined the prevailing pattern of the corporate structures underlying the bulk of the industry. About three-fourths of the business of the petroleum industry is conducted by companies engaged in all branches of the business, while the rest is transacted by units operating in only one or two divisions. Integration, however, is rarely complete even within the boundaries of the so-called integrated companies, so that the vast majority of companies are bounded to some extent by economic

[4] *American Petroleum Industry* (Amer. Petrol. Inst., New York, 1935), p. 18.

frontiers across which the flow of oil must pass. It is at these frontiers that the interplay of competitive forces is most intense.

If one were to construct an "economic map" of the industry, he would find that the boundaries of the economic entities would not

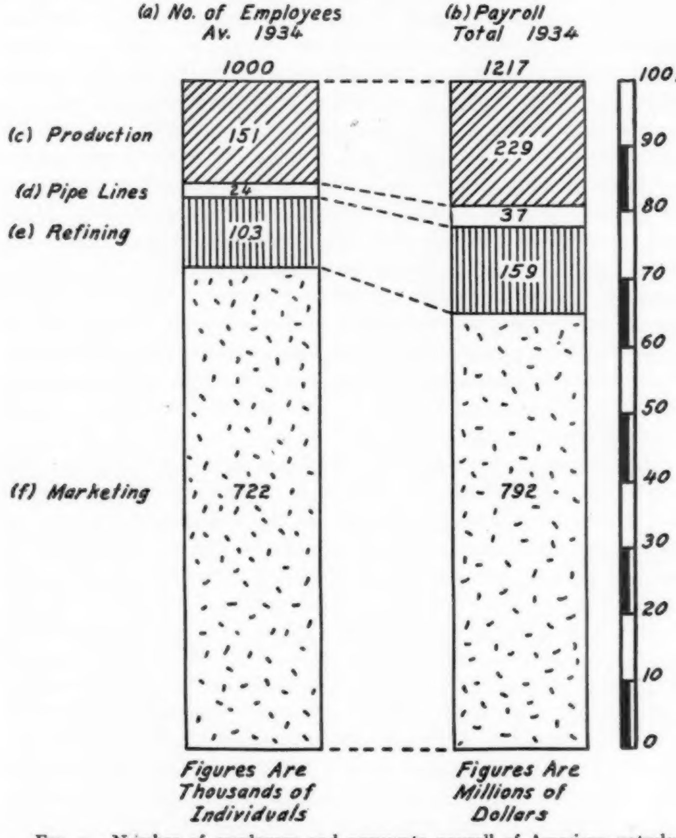

FIG. 1.—Number of employees and aggregate payroll of American petroleum industry in 1934. (Data compiled by Planning and Coördination Committee under the Petroleum Code.)

coincide with departmental or corporate limits, but would surround spheres of economic interest which might be labelled: the producer, the producer-refiner, the purchaser-refiner, the producer-refiner-marketer, the purchaser-refiner-marketer, and the purchaser-marketer. The structure of this assemblage is such that economic forces

are transmitted with unequal intensity through the several areas. The producer-refiner-marketer, for example, affords a conduit for the transfer of the pressure of low-cost production directly over into the price of products. The purchaser-refiner transmits the same pres-

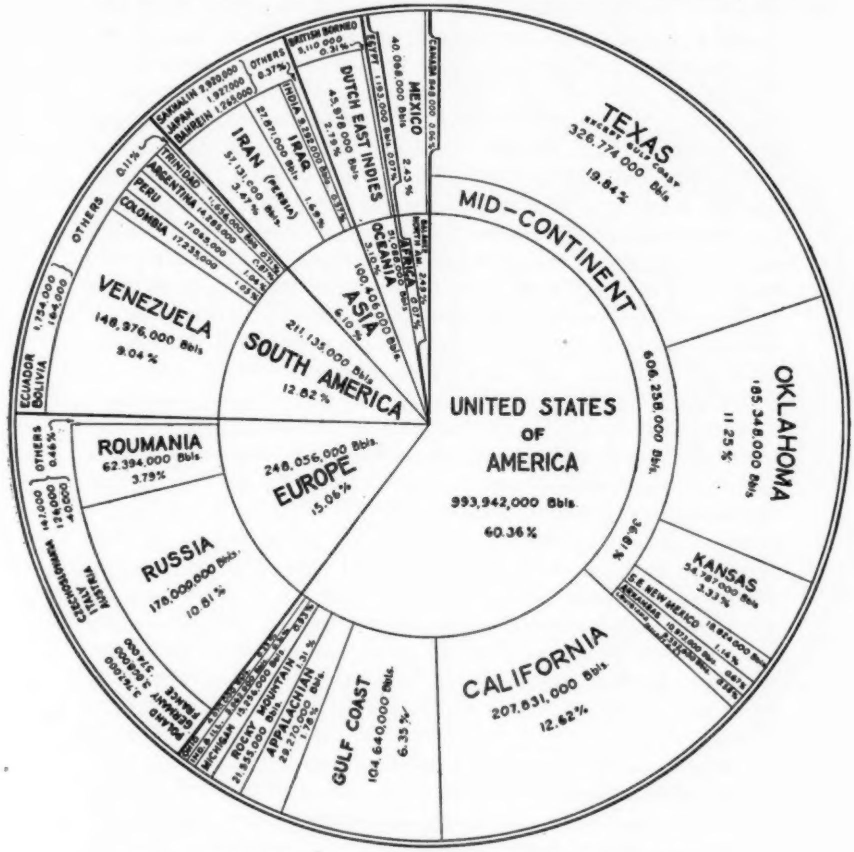

FIG. 2.—The world's crude-oil production in 1935, by countries and areas. (Courtesy of *The Lamp.*)

sure to a like end through the medium of cut-rate purchases of crude oil. The zone between the refiner and the purchaser-marketer is occupied by a barrier where the buyer and seller of gasoline at wholesale meet and create a relatively free market. The producer-refiner-marketer and the purchaser-refiner-marketer compete in the retail

market, with different costs; the one against the other and both against the purchaser-marketer.

In addition to its integrative tendency, the petroleum industry has assumed the general form of large-scale enterprise. Being by nature a "capital" industry, this activity has logically developed around nuclei of large and massive operations. Yet, despite the dominance of large units, or perhaps because of them, a condition of active competition has prevailed and changes in the industry have been rapid and progressive. The number of separate enterprises are fewest in refining and transportation, and greatest in production and distribution. The 1936 edition of the *World Petroleum Directory*, for example, devotes 12 and 27 pages, respectively, to a description of pipe line companies and refiners; but 169 pages to producers; and 276 pages to marketers. The oil industry, therefore, displays in this respect a sort of hourglass pattern, with the raw material drawn from numerous sources, concentrated in the processes of transportation and refining, and again spread out in the form of products through innumerable channels. This structure is consistent with the nature of the enterprise and the technologic factors available for its conduct.

Two other broad characteristics of the petroleum industry may be noted. Oil refining is a multiple-product operation, turning out a main product (gasoline) and a host of by-products. This feature creates difficulties in cost accounting and problems in balancing the supply of and demand for the by-products. The laws of joint-product prices are here invoked and technologic change is continuously stimulated. The petroleum industry as a whole is a type of activity that requires a large capital investment per worker. Thus the capital factor is more important than the labor factor. Two consequences flow from this circumstance: (a) the industry is particularly suited to operation by large aggregates of capital (not so true of the distributing division); and (b) the industry is especially susceptible to losses arising from the incidence of technologic change.

An important resultant of the large amount of capital employed in the petroleum industry is found in the wide and growing application of technology to the reduction of costs, improvement in process, and betterment of products. In few industrial fields have applied science and engineering methods been so assiduously developed and utilized. Geology, paleontology, geophysics, mechanics, metallurgy, and chemistry are drawn upon in large and increasing measure. To cite a prominent example, the American Association of Petroleum Geologists, founded in 1916 to promote the application of geology to oil finding and oil production, has a membership of 2,134[4a] and its

[4a] 2,330 in December, 1936.

monthly *Bulletin* is an invaluable contribution to theory and practice in this field.

A balance sheet of supply and demand for the American petroleum

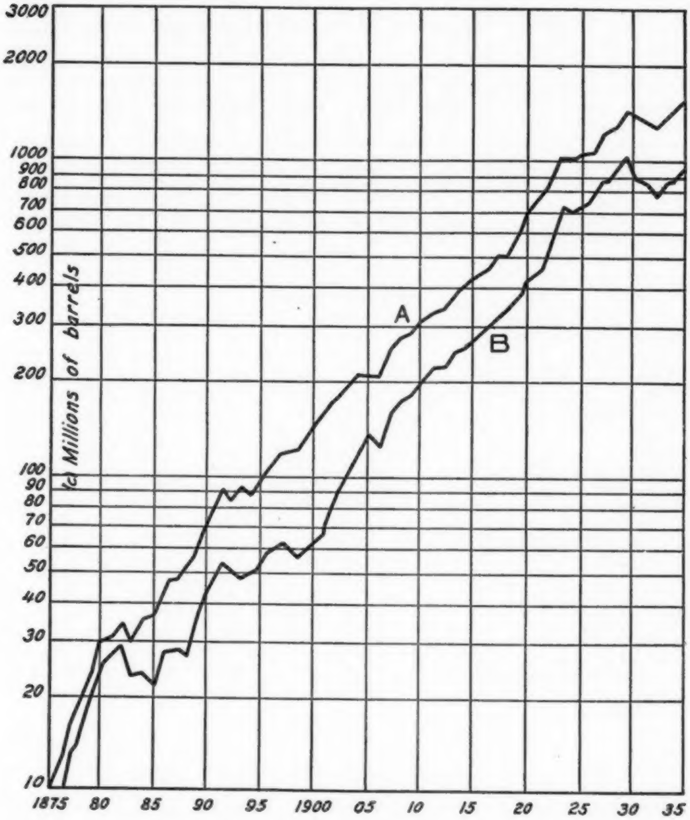

FIG. 3.—Rate of growth of crude oil production in the world and in the United States by years, 1875–1935.

(A) World.
(B) United States.
(*c*) Millions of barrels.

industry is presented in Table I, which shows for the past 6 years the trend and interrelationships of crude oil and its principal products.

EXPLORATION

Because of the hidden and elusive location of oil deposits, and the effort and cost involved in their discovery, the petroleum industry

TABLE I

Trend of Supply and Demand in the American Petroleum Industry by Years 1930 to 1935—Data from United States Bureau of Mines (In Millions of Barrels)

SUPPLY, ALL OILS

	1930	*1931*	*1932*	*1933*	*1934*	*1935*	*Per Cent Change 1935 from 1934*
Domestic crude	898.0	851.1	785.2	905.7	908.1	993.9	+9.2
Natural gasoline	52.6	43.6	36.3	33.8	36.5	38.9	+9.5
Benzol	2.7	1.8	1.0	1.4	1.7	1.9	+11.6
Imports, crude	62.1	47.3	44.7	31.9	35.6	32.2	−9.5
Imports, products	43.5	38.8	29.8	13.5	14.9	20.4	+37.0
Total supply	1,058.9	982.6	897.0	986.2	996.8	1,087.3	+9.1
Change in all stocks	−24.0	−45.0	+41.8	+11.0	−37.8	−22.4	—
Change in crude stocks	—	−41.0	−30.5	+15.4	−17.0	−22.6	—

DEMAND, ALL OILS

	1930	*1931*	*1932*	*1933*	*1934*	*1935*	*Per Cent Change 1935 from 1934*
Domestic							
Motor fuel	—	403.4	373.9	377.0	407.1	432.6	+6.3
Kerosene	—	31.3	33.2	38.5	44.2	47.7	+7.7
Fuel oil	—	334.7	308.2	316.3	332.0	352.7	+6.3
Lubricants	—	20.1	16.6	17.2	18.5	19.6	+6.0
Wax	—	1.0	.9	1.3	.9	.9	—
Coke	—	7.8	9.6	10.0	7.5	6.7	−10.5
Asphalt	—	14.7	12.7	11.8	13.9	16.4	+18.0
Road oil	—	5.1	6.6	5.3	6.4	6.8	+6.1
Still gas*	—	38.6	40.9	45.2	44.4	50.2	−13.0
Miscellaneous	—	3.9	2.0	1.5	2.1	2.1	—
Losses and crude used as such	—	42.6	30.9	44.5	43.2	45.9	+6.1
Total, domestic	926.5	903.2	835.5	868.5	920.2	981.6	+6.6
Exports, crude	23.7	25.5	27.4	36.6	41.1	51.4	+25.1
Exports, products	132.8	98.9	75.9	70.1	73.4	76.8	+4.6
Grand total demand	1,082.9	1,027.6	938.8	975.2	1,034.6	1,109.8	+7.3

* Production.

MOTOR FUEL, SUPPLY AND DEMAND

	1930	*1931*	*1932*	*1933*	*1934*	*1935*	*Per Cent Change 1935 from 1934*
Crude to stills	927.4	894.6	820.0	861.3	895.6	966.2	+7.6
Output							
Cracked gas	164.4	176.4	170.9	180.6	182.4	207.5	+13.7
Natural (net)	49.0	39.5	32.4	30.3	33.3	36.5	+9.5
Benzol	2.7	1.8	1.0	1.4	1.7	1.9	+11.6
Imports	16.9	13.6	8.2	—	—	—	—
Straight-run	224.6	220.0	195.4	195.6	206.3	219.6	+6.1
Total supply	457.6	451.3	407.9	407.9	423.8	465.5	+9.8
Change in stocks	−2.8	+2.2	−1.4	+1.3	−8.0	+2.5	—
Domestic demand	394.8	403.4	373.9	377.0	407.1	432.6	+6.3
Exports	65.6	45.7	35.4	29.3	24.7	30.4	+23.1
Total	460.4	449.1	409.3	406.3	431.8	463.0	+7.2
Per cent rec. straight-run	24.0	25.8	23.8	22.7	23.1	22.7	—
Per cent rec. straight-run and cracked	41.5	46.4	44.8	43.7	43.4	44.2	—

has never blocked out what might be termed large reserves of its raw material. Underground proven reserves of the order of 10 to 15 years' supply have been the rule, at least during the past 25 years, and hence a continuous stream of discovery has been necessary to maintain this working stock. Indeed, search for new deposits is an essential

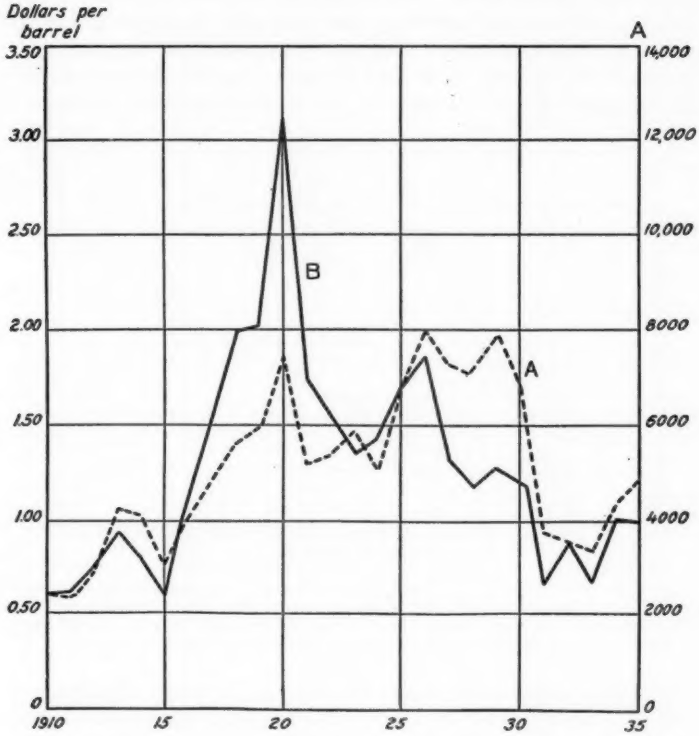

FIG. 4.—Correlation of weighted average price of crude oil and number of dry holes drilled by years, 1910–35.
(A) Dry holes.
(B) Price.

part of the production enterprise and must be initiated and conducted several years in advance of current requirements to insure a continuity of supply.

Exploration for crude oil, picturesquely termed "wildcatting," is of two general types—random and scientific—and both kinds appear to be essential, despite the imposing advances made in recent years in

the technique of exploration. The science of geology, fortified of late by the science of physics, has directed an increasing proportion of the exploratory effort and influenced the random phase; but the problem of maintaining discovery is not believed by those charged with the responsibility to be solvable entirely by scientifically directed campaigns but on the contrary requires a multiplicity of effort and a flexible approach in order to bring into view the "unorthodox" occurrences. Discovery is a function of the quantity of effort and its caliber; of the number of wells drilled and the skill employed in their location; of the capital and technology employed. Both elements fluctuate in

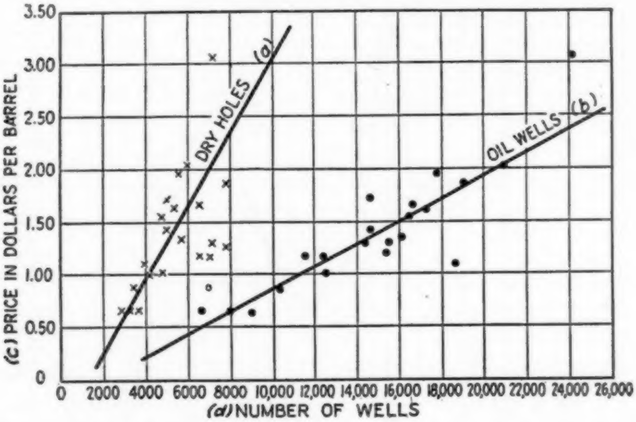

FIG. 5.—Correlation between weighted average price of crude oil and (a) number of dry holes drilled, and (b) number of oil wells completed—the indexes respectively of wildcatting and development of effort. Data are for years 1915–35. (After Pogue, American Institute of Mining and Metallurgical Engineers, 1936.)

availability, under the influence of price, while the technological factor, under competitive effort, has pursued a geometric course of advancement. The progress in the technology of oil exploration forms a brilliant, but scarcely appreciated, chapter in industrial enterprise; the most academic and abstruse phases of scientific technique have been requisitioned and turned to practical account, such as micropaleontology, seismic phenomena, and electrical conductivity; while the core barrel, the electrical log, the torsion balance, the magnetometer, the aerial camera, and the seismograph are but a few of the devices that are used to gather clues for the effectuation of discovery.

No entirely satisfactory index of search is available, but the number of dry holes drilled constitutes an acceptable measure of the

volume of effort going into exploration. These figures are available for the entire period that the industry has operated. This index of wildcatting effort is strongly influenced by price, as indicated by the graphic correlations presented in Figures 4 and 5. Price, therefore, operates as a regulator of the volume of effort, but there are other elements in the equation that do not respond so readily to price—improvements in the art, the chance element in respect to time, and the varying size of fields—and hence there appears to be no practical way in which discovery can be planned or regulated so as to be kept in balance with requirements. This circumstance constitutes a problem

TABLE II

TREND OF CRUDE-OIL DISCOVERIES AND NET ADDITIONS TO PROVEN CRUDE-OIL RESERVES IN THE UNITED STATES BY PERIODS, 1859 TO 1935, COMPARED WITH PRICE AND WILDCATTING EFFORT (NUMBER OF DRY HOLES DRILLED)

Period	*Production**	*Crude Oil Discovered†*	*Change in Reserve*	*Reserve End of Period*	*Average Price Crude‡*	*Number of Dry Holes Drilled§*	*Oil Discovered per Dry Hole*
	Million Barrels	*Million Barrels*	*Million Barrels*	*Million Barrels*	*Per Barrel*		*Barrels*
1859–1900	1,004	3,360	+2,356	2,356	$1.02	32,009	105,000
1901–05	510	1,700	+1,190	3,546	.82	18,057	94,000
1906–10	864	1,375	+511	4,057	.69	16,406	84,000
1911–15	1,239	2,500	+1,261	5,318	.75	16,623	150,000
1916–20	1,813	2,925	+1,112	6,430	2.03	27,853	105,000
1921–25	3,240	4,100	+860	7,290	1.54	28,153	146,000
1926–30	4,479	9,950	+5,471	12,761	1.35	36,893	270,000
1931–35	4,444	4,120	−324	12,437	.83	19,763	208,000
Total	17,593	30,030	+12,437	—	1.21	195,757	153,400

* Data from U. S. Bureau of Mines.
† Data for 1859–1934 from Wallace Pratt, *op. cit.;* 1935 estimated by writer
‡ Weighted according to volume produced.
§ Data from *Oil and Gas Jour.*

in industrial equilibrium which must be solved indirectly, for it would be hazardous in times of oversupply to place artificial restraints on search; such efforts might appear logical for the short term but they would tend to create shortages in the future.

Thus discovery, the objective of all exploration, is a function not merely of the volume of effort, but of its calibre, with a chance variant in respect to time coming into account. Hence we find an all too imperfect correlation between price and rate of discovery. Table II shows, for 5-year periods, the rate of discovery in the United States in comparison with the rate of production and the rate of search (as indicated by the dry-hole index). For the entire life of the American industry, 153,400 barrels of oil have been discovered per dry hole

drilled, and the range of response to the volume of effort has been from 84,000 barrels per dry hole to 270,000 barrels per dry hole, a wide amplitude. The tabulation shows further an upward trend in the response to effort, reaching a high point in the 1926 to 1930 period, but not declining drastically in the ensuing 5-year period. This trend is undoubtedly caused by improving technology: geology, geophysics,

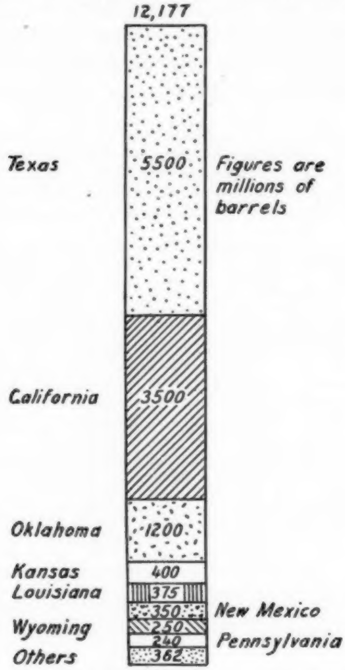

FIG. 6.—Indicated proven crude-oil reserve on December 31, 1934. (Data from Committee of Petroleum Geologists, see *American Petroleum Industry*, 1935, page 35.)

and the like. For the past 15 years, the discovery response has been 214,000 barrels per dry hole. Accordingly, the way to discover 1 billion barrels of oil is to drill 5,000 dry holes! There is no difficulty involved in the marshalling of the requisite effort, provided prices are flexible; but there is a necessity for retarding drilling in times of overdiscovery, if low prices are to be avoided. Price is the customary governor under such circumstances, but under the operation of proration

(as we shall discuss later), other measures are possible to act as a brake on drilling.

Table II indicates further that a concentration of discovery took place in 1926 to 1930, forming the setting in which the institution of proration was established. In that period about 10 billion barrels of oil were found, of which about 5.5 billion went to the augmenting of the proven reserve. It is worthy of note that over half of the reserve increment was contributed by a single superpool, East Texas, which is of interest in three particulars: (*a*) East Texas was discovered by a random well; (*b*) the field should logically have been found in the middle twenties; and (*c*) this deposit is unparalleled in size and ultimate yield (estimated at 3.5 billion barrels). These circumstances emphasize the importance of random wildcatting, the chance element in respect to time, and the degree of concentration, in their bearing upon the problem of industrial equilibrium. It is natural that the absorption of this massive reserve into the oil economy, at an inopportune time, necessitated such radical changes in trade channels that the functional aspect of price had to be invoked in accomplishing the assimilation.

The size of the proven reserve of crude petroleum in the United States is estimated by the best authorities to be in the neighborhood of 11 to 13 billion barrels. The Petroleum Administrative Board of the United States Department of the Interior estimated the reserve of recoverable oil in the United States on December 31, 1934, at 10.8 billion barrels.[5] A committee of petroleum geologists, at the request of the American Petroleum Institute, in late 1935 estimated the proven reserve at 12.2 billion barrels as of December 31, 1934[6] (Fig. 6). The writer's estimate for January 1, 1936, based largely upon a cumulation of Pratt's rate of discovery figures as shown in Table II, indicates a proven reserve of 12.4 billion barrels. These figures all relate to the volume of oil estimated to be recoverable from known fields by present methods at approximately present prices. Rises in price or improvements in technique, or both, would greatly augment the volume of recoverable oil. Also, none of these estimates includes the unknown, but doubtless very great, volume of oil yet to be discovered.

Estimates of the proven reserve of recoverable oil have been made periodically, and invariably these studies have aroused interest in

[5] *Report on the Cost of Producing Crude Petroleum* (U. S. Department of the Interior, Washington, 1935), p. 133.

[6] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), p. 4. Also see, *American Petroleum Industry* (Amer. Petrol. Inst., New York, 1935), p. 35.

the seeming smallness of the proven reserve, as expressed in number of years' supply, which in recent decades have ranged from about 10 to 15 years' supply. The inference has frequently been drawn that a shortage was impending. The proven reserve, however, is not the ultimate reserve, but is merely the volume of blocked-out oil that the industry, under the circumstances prevailing, has brought into sight. The size of the proven reserve gives no clue whatsoever to, and logically cannot be expected to reveal, the imminence or remoteness of

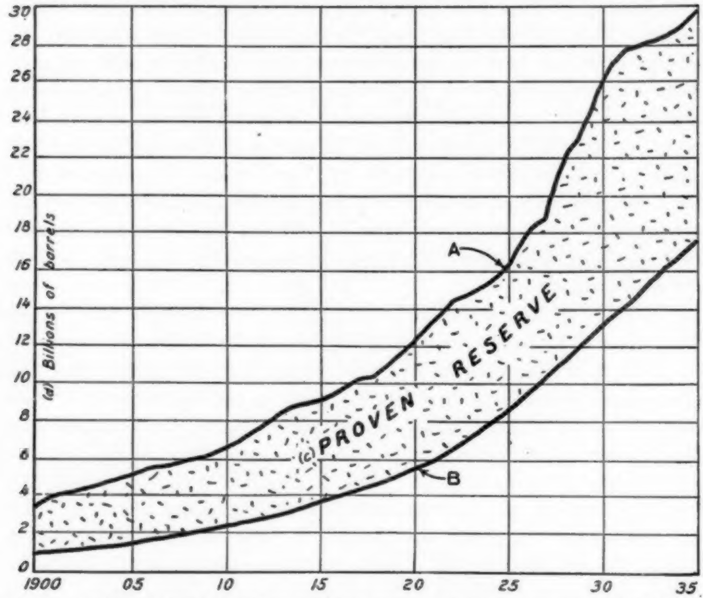

FIG. 7.—Indicated tiend of proven crude-oil reserve by years, 1900–35. (After Committee of Petroleum Geologists, see *American Petroleum Industry*, 1935, page 38.)
(A) Accumulated discoveries.
(B) Accumulated production.

scarcity. The proven reserve is in the nature of a working stock, or working reserve[7]; the true reserve is a variable with an unknown, and unknowable, component. The only basis for anticipating a scarcity is by means of reasoning on the principle of elimination; that each pool found means one less to be discovered in the future; but the sheer size of the proven reserve sheds no light upon the number of pools yet to be found, or the possible commercial enlargement of existing pools.

[7] The optimum size of the reserve depends upon the nature of drilling and production rates. A larger reserve is needed under restricted flow than when the rule of capture has free play.

Figure 7 shows the development of the reserve as a widening belt between the cumulative curves of production and discovery. A glance at this chart will convey the impression that the proven reserve is a working stock, and that no weakening in the trend is indicated by the data. On the contrary, the symmetry of the belt suggests that its widening, due to accelerated discovery in the late twenties, was abnormal and confirms the thought that the disequilibrium so created provided the occasion for the development of proration.

The important matter, therefore, in this respect, is not the size of the proven reserve but the effective magnitude of the ultimate reserve. No answer can be given on this point in a quantitative sense. Indeed, the problem is not so much one of finding a way of drawing aside the veil that obscures the future, as it is of maintaining an economic mechanism that will handle any contingency. The committee of geologists, previously referred to, after considerable deliberation, reached this conclusion:[8]

> Large areas within the United States, underlain by sedimentary rocks, are only partly explored for oil reserves, whereas the areas already explored by the best current methods are relatively small. No satisfactory method has been found for assigning a numerical estimate to the amount of oil recoverable from undiscovered deposits. The oil to be discovered in the future is so concealed from observation that an estimate of ultimate reserves in terms of barrels is obviously impracticable. However, we do have a definite, although incomplete, knowledge concerning the existence in an important part of these slightly explored areas of extensive deformation in sedimentary rocks which are productive in neighboring districts, of deeper prospects, and of other geologic factors which are favorable to the occurrence of oil. This gives reason to expect that ample discoveries will be made to meet national requirements for a period of indeterminate length. There is no evidence that discoveries will not continue to be made for many years.

In his presidential address[9] before the American Association of Petroleum Geologists on March 19, 1936, A. I. Levorsen, after considering the dominance of anticlinal oil in past discoveries and viewing the future potentialities of flank sands, regional unconformities, and up-dip wedging of porosity as oil reservoirs, expressed this opinion:

> One does not appreciate the possibilities of this sort of geology until time and thought have been given to it, and I venture to say that upon investigation you will each of you reach the conclusion, as I have, that there are yet to be discovered oil and gas reserves almost without limit by those who may

[8] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 8–9.

[9] "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (May, 1936), pp. 529–30.
Oil and Gas Jour. (March 26, 1936), pp. 41, 42, 44, and 48.

become adept in stratigraphic analysis. . . . Differing from our past methods, the possibilities for stratigraphic production cannot be quickly exhausted. . . . The day of geology, as applied to the practical problem of discovering a continuing oil reserve for our Nation, is just dawning. There can be no doubt that an abundance of oil in terms of national demand remains to be discovered.

One can foresee, however, a development that may readily be misinterpreted when it arises. The number of oil-bearing structural traps, which harbor our orthodox oil fields, is limited and the remaining ones are rapidly being found.[10] The time will come when a transition will be necessary to a more active search for the unorthodox, or stratigraphic, occurrences; and this change, heralded by a rise in price, will almost certainly be confused by the casual observer with an impending shortage. Under such circumstances a moderate price advance can be expected to stimulate the increased scope of drilling and intensified application of geological principles to carry supply into this new phase. It should be recognized that a flexible price structure, active competition, and multiple effort are the only economic instrumentalities necessary to gain the optimum discovery of the raw material. Barring the introduction of artificial rigidities at the source, the problem is likely to remain with but few interruptions; how to retard the overdrilling of discoveries in order to prevent the freezing of capital in unneeded potentials.

PRODUCTION

The production of crude petroleum, under conditions prevalent in the United States, involves a stubborn economic problem, or rather an issue that became obdurate when the industry matured and technological progress reached a state of high proficiency. This problem is the resultant of the asymmetrical character of the production mechanism; that is to say, the mechanism is such that it accelerates more readily than it retards. The principal cause of this unbalanced reaction is the incidence of a special type of competition, arising from a legal technicality, superimposed upon the normal elements of industrial competition. This anomaly is the rule of capture, which ascribes ownership not to the oil in place but only to the oil when reduced to possession. Thus, wherever an oil field is composed of areas of divided ownership, drilling is motivated not by economic conditions (as re-

[10] In a paper presented before the Tulsa meeting of the Institution of Petroleum Technologists in May, 1936, E. DeGolyer, a leading student and practitioner in the field of oil discovery, stated that in a few years all structural accumulations of oil that can be located by geophysical methods will have been found and it will be necessary to adopt other methods to locate oil in other types of accumulations. This will necessitate a more detailed study of subsurface formations for correlating data and will necessitate the drilling of many exploratory wells. *Oil and Gas Jour.* (May 21, 1936), p. 27.

flected in price) but by the necessity imposed upon each operator to capture his oil before it is drained by his neighbor. As a result of this circumstance, oil fields tend to be drilled rapidly and without due regard to the requirements of approved engineering practice and the needs of the market.

During the greater part of the life history of the American petroleum industry, perhaps up to as late as 1920, the rule of capture, with its compounding effect upon competition, was not a wholly unsatisfactory factor in production. It gave speed to the enterprise, supporting and sustaining the rate of expansion that the requirements of consumers demanded. It led to serious wastes, too, for it was antipathetical to the best engineering practice; but these wastes must be looked upon largely as the price paid for rapid growth, a cost that society was presumably willing to incur as preferable to delay. At the same time it was inevitable that the rule of capture would eventually become untenable, once the conjuncture of maturing demand and advancing technology was capable of creating equilibrium without the extraneous aid of interlease competition. At exactly that conjunctural point, the rule of capture became superfluous and since that time the economic organism has been in process of eliminating this factor from its mechanism. Intrenched in law and in custom, the process of its eradication has been slow and indirect, unperceived by most observers. For the past 10 to 15 years there has been a gradual weakening of interlease competition and a progressing tendency for oil fields to be operated as units, or as if they were units, with inestimable gain in operating efficiency and great reductions in physical wastes. Considerable distance is yet to be traveled, but the trend is in the right direction and even in the brief time in question a revolution in the *modus operandi* of the producing division has taken place.

It is generally accepted that the most efficient way to operate an oil field is as a unit. Not only does technology thus have free scope but there is admitted no uneconomic interlease competition leading to physical wastes. Were all fields operated as units, competition would be confined to cost-competition and thus would be wholly desirable. It is evident, further, that the rule of capture has no existence under unit operation. The industry has made considerable headway toward unitization of oil fields, but the legal handicaps have been severe and progress in this direction has not been capable, alone, of meeting the requirements of equilibrium. The supplementary expedient has been the development of the intricate mechanism known under the name of proration.

Proration may be interpreted as a means for mitigating the effects

of the rule of capture. It has appeared on the scene at various times in the past, during temporary periods of oversupply, only to disappear again when equilibrium reestablished itself. Proration, however, only assumed the status of an institution, grounded in State conservation laws, when oversupply became chronic; that is, when equilibrium could not be regained under the free operation of the rule of capture. As is well known, proration, as we now know it, was initiated in Oklahoma in 1926 and from that beginning has expanded until it has now become the accepted procedure in all important producing areas of the country.[11]

Proration has developed as a compound mechanism, comprising two distinct but related functions—a restriction on the rule of capture and a production control. These two elements are inextricably bound up, the one with the other, and the two aspects are not always clearly perceived. The production-control function has probably been overemphasized to the obscuration of the physical effects of proration in the direction of permitting oil fields to be produced slowly, under back pressure, so as to maintain underground equilibrium, instead of rapidly under open flow with the consequent premature dissipation of the reservoir energy. The legal framework upon which proration rests involves the conservation statutes of the various oil-producing States, which primarily relate to the prohibition of physical waste but are evolving in the direction of including economic waste as well. The States more advanced in attention to the subject have developed creditable conservation laws and further progress is under way, both in the improvement in the basic laws in the more backward States, as well as in the interpretation of existing laws by the courts.

The physical aspects of proration center around the principle of ratable takings, which is an approach to the concept of the ownership of oil in place. The procedure of ratable takings is merely that of requiring each operator of a lease within a pool to regulate his withdrawals according to some function of the lease—usually the aggregate initial production of his wells (an index of his potential capacity to produce); occasionally some combination of potential and acreage, such as the per-well average instead of the aggregate potential. The introduction of the acreage factor is most important, for it removes the incentive to drill too many wells and brings withdrawals nearer to a true proportion of the oil in place. Further evolution in the ratable takings formulas is under way. The absence of the acreage factor

[11] For a detailed account of the earlier development of proration, see L. M. Logan, Jr., *Stabilization of the Petroleum Industry* (University of Oklahoma Press, Norman, 1930). For a discussion of the economics of proration, see J. E. Pogue, "Economics of Proration," *Petrol. Devel. and Tech.* (Amer. Inst. Min. Met. Eng., 1932), pp. 69–76.

creates inequities and promotes uneconomic drilling, for it permits a segment of the rule of capture to operate. The State conservation statutes also carry the power to regulate the spacing of wells; and the development of fields according to planned patterns of spacing, adapted to the reservoir conditions, represents a marked advance over the practice imposed by the rule of capture, which tends to result in too many wells. Additional progress needs to be registered in controlled well-spacing, which not only offers economies in operation but also contributes to the maintenance of equilibrium between supply and demand.

The economic aspect of proration has to do with the limitation of crude oil production to quotas established for pools and States. In order to regulate withdrawals from leases to a ratable basis, it is necessary to set up an allowable rate of output for the pool. This base rate must not be higher than a certain optimum, for a greater rate creates a disturbance of underground equilibrium manifesting itself in improper declines in reservoir pressure, which results in underground waste. Were all pools restricted to their optimum rates of production, and proper ratable takings enforced in each, then the requirements of operating efficiency would be met. The system of regulation could be terminated at this point, with no pool permitted to exceed its optimum rate; but, as a matter of practice, competition between pools would tend to break down the equilibrium and hence State quotas are set up to serve as a base for limiting the pool quotas to an aggregate that does not exceed the requirements of the market. In the earlier stages of proration, each State independently established its own State allowable, but competition between the States was found to result in an aggregate production for the Nation in excess of the requirements of the market. Hence the next step was the development of means for harmonizing the State quotas. This coördination was first provided in 1930 as a result of reports initiated by a volunteer committee on economics under the auspices of the Federal Oil-Conservation Board, was made mandatory under the operation of the Petroleum Code, and is now supplied by the United States Bureau of Mines in the form of recommended quotas issued each month. The newly formed Interstate Oil Compact offers another instrumentality for the work of coördination, but thus far this agency has not progressed to the point of dealing with the economic function.[12]

Since the quotas computed by the United States Bureau of Mines

[12] The Connally Act, passed by the Congress to apply to the period February 22, 1935, to June 16, 1937, and forbidding the movement into interstate commerce of any oil produced in excess of State allowables, proved useful in checking traffic in "hot" oil through the activities of a Federal Tender Board.

are merely advisory, there is at times a tendency on the part of some States to exceed the recommended figures. Whenever these excesses, however, go beyond critical limits the price structure must suffer, because the calculations are based upon existing trade channels which cannot be altered rapidly except with the accompaniment of price changes. A proper function of price, under such circumstances, is to regulate the action of the States. The Bureau of Mines quotas are calculated on the basis of a balanced situation, taking into account proper changes in stocks of crude oil and products, and seasonal variations in demand. This quota system, therefore, provides a mechanism for balancing supply with the consumer-demand for products, thus avoiding the disrupting influence of intermediate speculative or inflationary movements. The importance of these quotas is gradually becoming appreciated in the industry and they will contribute a stabilizing influence in proportion to the extent that they are accepted by the State commissions as evidences of demand.

The institution of proration has thus modified the mechanism whereby supply and demand is equated. Formerly subject to regulation by price alone, supply is now restricted at the wellhead by proration which therefore acts as a substitute for price at this point in the system. Price, however, is not thereby rendered inoperative in its functional capacity but is merely moved to a sidewise position, so to speak, where it continues to influence demand and the sequence of events—search, discovery, and drilling—that lies back of production proper. The relation of price to the various elements is illustrated in Figure 8. At present the operation of proration permits supply to accumulate in potential form behind the barrier of proration, which tends to create a condition of strain and unbalance if the process is carried too far. It was primarily the rise of the so-called potential in the period 1929–31 that led to the collapse of the price structure in that period. The building up in any field of a potential in excess of that required to maximize the utilization of reservoir energy and to minimize costs represents a fixation of capital in nonproductive form that should be avoided. The next step in the development of proration should be the more active furtherance of means to prevent the drilling of unnecessary wells, such as improved formulas for ratable takings, controlled well spacing, and other instrumentalities for gaining the efficiencies possible under unit operation. Some progress in this direction has already been registered, despite formidable difficulties such as the rigidities of lease requirements and the subtleties of the issue; but the rise in capital requirements coincident with declining

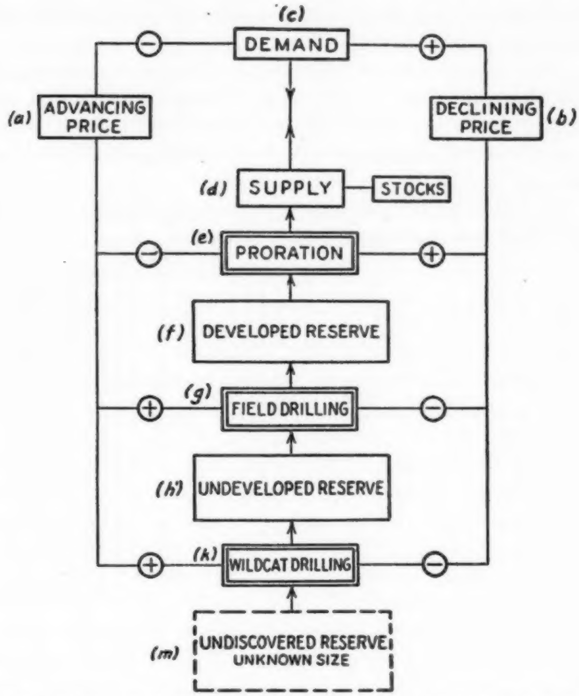

FIG. 8.—Diagrammatic sketch of economic structure of petroleum industry under proration, showing effect of price upon various parts of the system. (After Pogue, American Institute of Mining and Metallurgical Engineers, 1936.)

per-well allowables is gradually forcing to this problem the attention its importance deserves.[13]

In a recent article[14] the writer has suggested the following approach

[13] An interesting example of the proration concept among oil-company executives is found in two papers delivered in May, 1936, respectively, before the midyear meeting of the Independent Petroleum Association of America and the Mid-Continent Section of the American Institute of Mining Engineers: "Some Economic Aspects of Proration," by John M. Lovejoy, president of the Seaboard Oil Company; and "Economics of Oil Producing Practice," by C. H. Lieb, president of the Carter Oil Company. Mr. Lovejoy recommends the development of new reserves with a minimum number of wells, favors wide well spacing, advocates the recognition of an acreage factor in lease allowables, and stresses the importance of the Bureau of Mines' quotas. Mr. Lieb favors wider well spacing, unitization, and pressure maintenance as standard operating practices; advocates modification of the rule of capture so as to permit, "and whenever possible . . . to compel," the foregoing practices; and believes that proration should be based upon an allowable per well "coincident with a rate of withdrawal utilizing the reservoir energy to the greatest degree of efficiency."

[14] *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 118 (1936).

to the strengthening of the proration mechanism, to enable it to lessen the incidence of unnecessary drilling:

1. Furtherance by the petroleum industry of a consistent policy of relatively low oil prices so long as potentials are large and the discovery rate shows any tendency to exceed the production rate; so long, too, as a maximum demand is a desideratum in maintaining balance.

2. Promotion by the petroleum industry of retarded field drilling through wider well spacing and unit operation.

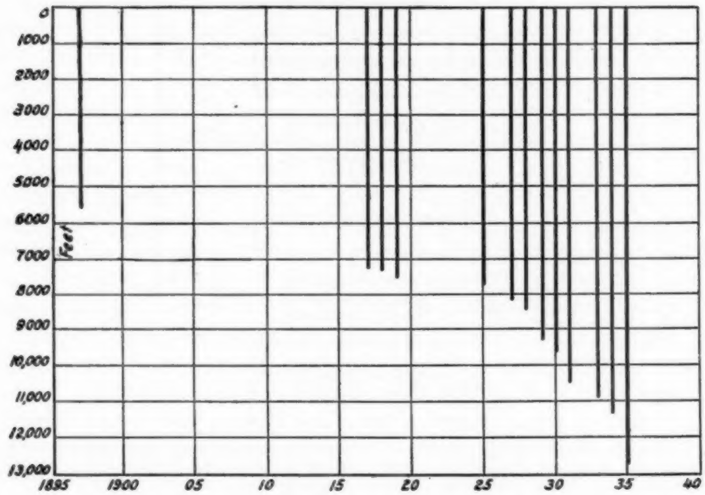

FIG. 9.—Trend of drilling depths in United States by years, 1897–1935, indicated by deepest wells completed. (Data from E. DeGolyer.)

3. Advocacy by State regulatory bodies of formulas for lease allowables that will normalize, and not overstimulate, drilling. The acreage factor will accomplish this result.

4. Support by State regulatory bodies of prescribed programs of wide well spacing.

The improvements in production methods over the past 10 to 15 years have been scarcely less striking than the economic changes that have transpired in this field. Depths commercially reachable by the drill have been more than doubled, and a 10,000-foot hole is no longer a novelty (Fig. 9). The proportion of oil recovered from the sand has sharply increased and the knowledge and utilization of reservoir pressures have been greatly augmented. Ingenious methods have been

developed for going back and reworking depleted fields; in the old Bradford field of Pennsylvania, for example, pressure flooding has commercially developed a larger reserve of oil than was extracted during the past 60 years by conventional flowing and pumping. The achievements in the field of production engineering, indeed, have been almost as notable as those in the art of exploration. The two combined represent a factor that has contributed signally to the reduction of costs and the enlargement of the available supply, and has gone far toward offsetting the physical losses involved as a result of interlease competition under the rule of capture.

According to the Petroleum Administrative Board[15] of the United States Department of the Interior, which has made an exhaustive accounting study of the cost of producing crude oil in the United States, the average production cost was 86 cents per barrel in 1931, 81 cents per barrel in 1932, 71 cents per barrel in 1933, 80 cents per barrel in 1934, and 80 cents per barrel as the average for 1931 to 1934. A previous investigation by the United States Tariff Commission on an approximately comparative basis for the period 1927 to 1930, showed a weighted average cost of $1.07. Thus a reduction of 25 per cent in average production cost is indicated. The first-named study was based upon questionnaires sent producers, but returns were compiled for companies representing for the entire period 73 per cent of the national production and 50 per cent of the average number of wells under operation. It is apparent, therefore, that the production omitted from the study was for the most part from small, high-cost wells; and therefore the results are not representative of the entire industry. For the entire period, and covering the production reported, it was found that 10 per cent of the oil had a production cost of under 40 cents per barrel; 50 per cent of the oil, from 40 cents to 79 cents per barrel; 25 per cent of the oil, from 80 cents to $1.19 per barrel; and 15 per cent of the oil, from $1.20 to $4.40 per barrel and above. These figures reveal a wide amplitude in production costs, which is caused primarily by the greatly varying size of wells. This cost range, of course, constitutes a difficult problem in utilizing price alone as a regulator of production. Prices disastrous to stripper wells are required to render the flow of large wells uneconomic. An unsolved problem in the theory of crude oil costing is the cost of replacing the produced oil by means of new discoveries. Accounting systems in vogue do not resolve this question. In the long run, replacement cost must be the deciding factor in the price of crude oil.

Figure 10 shows from the inception of the industry to the present

[15] *Report on the Cost of Producing Crude Petroleum* (Washington, 1935).

time, the weighted average price of crude oil by years compared with an index of 30 basic commodities, both series having a common base of 100 for the 5 pre-war years, 1910–14. This record indicates a general tendency for the price of crude oil to conform to the course of other basic commodities, the departures therefrom being temporary. There is a tendency for demand to be the controlling factor in the broader price movements, while supply dominates for the short term. A glance at Figure 10 reveals the character of the price response to the inflation periods of the Civil War and the World War; also the relatively high prices prevailing during the twenties. During the period of proration, 1927–35, the price of crude oil averaged $1.01 per barrel, with a range in annual averages of 65 cents to $1.30. There is a predisposition in many quarters to judge the success or failure of proration by the price resultant. This view overlooks the functional nature of prices. Even with proration affecting supply, price fluctuations should play an important role in maintaining equilibrium. It would be a mistake to expect proration to create a stable price under all circumstances; on the contrary, a flexible price should be invoked to maintain the effectiveness of proration.

TRANSPORTATION

Crude oil is transported by means of special facilities created by the industry. The two principal types of conveyances used are the pipe line and the oil tanker. Only a fraction of the crude oil produced is carried by the railroads because pipe lines and tankers offer superior efficiency and lower costs.

For liquids available in sufficient volume, the pipe line affords the most efficient form of overland transportation. The capital costs are relatively low; rights-of-way are not expensive; the operation of the system is automatic to a high degree; movement is continuous; and there is no problem of two-way traffic or return movement of empty facilities. Because of these advantages and the technical proficiency of modern pumping systems, the average cost of pipe-line transportation probably does not exceed 4 mills per ton-mile, which contrasts with an average cost of moving railroad freight approximately 1 cent per ton-mile. Thus no natural competition can persist between oil pipe lines and the railroads.

The oil pipe lines of the United States constitute a far-flung system connecting the oil fields with the principal consuming centers and water terminals. The aggregate length of lines is in excess of 112,000 miles—over a third of the combined length of all important railroads. Oil pipe lines penetrate or traverse 24 States, but as the system is

below ground and only marked by an occasional pumping station, its magnitude and importance is not commonly realized. The system consists of trunk lines and what are known as gathering lines which connect with the flow tanks of individual oil wells. The pipe line, therefore, forms a link between the oil fields and refineries and the flow of oil is practically continuous from lease to plant.

Pipe lines are by nature large-scale enterprises. The Interstate Commerce Commission in its most recent report on interstate pipe-

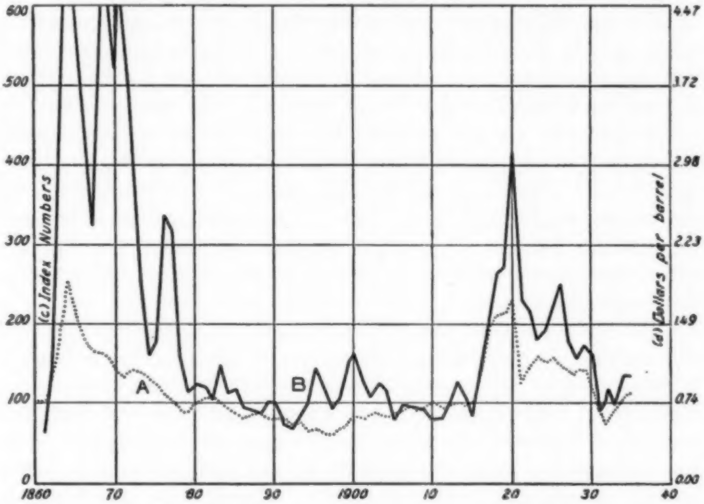

FIG. 10.—Weighted average price of crude oil in the United States compared with price of 30 basic commodities by years, 1865–1935, expressed in index numbers with a base of 100 for the period, 1910–14. (After Pogue, American Association of Petroleum Geologists, 1936.)
(A) Price of 30 basic commodities.
(B) Price of crude oil.

line operations lists only 53 companies, which represent about 81 per cent of the pipe-line mileage of the country, the remainder being intrastate systems not subject to regulation by the Commission. The 53 companies in 1934 represented a total investment of 815 million dollars (with accrued depreciation of 377 million dollars); transported 593 million barrels of oil originating on the lines, or 1,214 million barrels including duplications; and employed 20,853 men with an annual pay roll of 32 million dollars. The interstate systems, as well as the lines operating within a single State, are for the most part subsidiaries of integrated oil companies. Of the 53 units listed in the

Commission's 1934 report, only 9 are not affiliated with refining companies, and these independent lines are, with 4 exceptions, very short systems and represent only 10 per cent of the total trunk-line mileage of all interstate lines. Pipe lines have almost invariably been constructed by refining interests, who looked upon them as an adjunct to the manufacturing enterprise necessary to insure a continuity of raw material, a partial offset to the variable and shifting nature of crude oil production; they have rarely been built by producing interests or by promotors not already engaged in the oil business.

The first oil pipe line was constructed in Pennsylvania about 60 years ago. As the industry developed in the Appalachian area, pipe lines were extended to connect the oil fields of that region with refineries established in a number of large cities in Ohio and Pennsylvania. In 1878, a trunk line was completed to the Atlantic Coast. With the westward migration of the industry into the Middle West and then into the Mid-Continent, pipe-line construction followed oil discoveries and by 1913 the system, as we know it today, was outlined, permitting the shipment of oil from the western fields to the great refining centers of the Eastern Seaboard, the Gulf Coast, and the North Central States.

The development of the oil pipe line played an important role in determining the geographic pattern assumed by the refining division of the industry. The manufacturing plants were enabled to locate in populous centers, distant from the sources of the raw material; and new discoveries were quickly rendered available to them by new line construction, thus supporting the rapid expansion requisite to the growth of automotive transportation. Though now practically a country-wide system of specialized transport, the pipe line originated as a plant facility, and few refining establishments have been constructed outside of the oil fields or away from deep water without their own pipe-line connections. The economic union of the pipe line and the refinery is one of the oldest and most persistent attributes of the industry.

In its continuous pursuit of new sources of supply, the pipe line brings the market for crude oil to the oil fields. The pipe-line companies as such do not buy oil, but they serve as transportation agencies for purchasing companies acting on behalf of affiliated refineries. It is the integrated nature of the typical pipe line, therefore, that is responsible for the field location of the market. In this respect, crude petroleum differs from most other commodities which must seek their exchange in central markets. Crude oil does not come to market; the market goes to the crude oil. Perhaps this is the fundamental

reason why there has never developed a successful central exchange for this commodity.

With the evolution of proration, the presence of integrated pipe lines and a posted market at the well greatly facilitated the practical operation of the mechanism of control. Experience has shown that in areas resistant to the effective administration of proration, circumvention of the allowables has usually been brought about by the development of new channels of movement via rail or through nonintegrated pipe lines established for opportunistic purposes. There can be little question but that the integrated nature of the industry has contributed to the progress in scheduled production that has been brought about. A divorcement of pipe-line ownership from the oil industry proper would tend to impair the machinery of oil-field regulation and to act as a destabilizing influence upon the price structure.

Pipe lines function as common carriers in cases where demand for this service exists, although the bulk of the oil is still moved for the account of affiliated refineries. In recent years, there has been a tendency for two or more companies to unite in the construction of joint facilities. Pipe lines charge specified rates for the movement of oil, which are usually less than half the railroad freight rates, and these tariffs for interstate movements are under the supervision of the Interstate Commerce Commission. Pipe-line rates do not carry the economic significance usually ascribed to them, for they are merely bookkeeping concepts for integrated companies; but the general downward tendency in rates in evidence in recent years has exerted some influence through nonintegrated channels in the direction of furthering overproduction.

In recent years the technique of pipe-line haulage has been successfully applied to the volatile product, gasoline, but the volume moved through pipe lines is only about 9 per cent of the quantity of crude oil transported in this way, and around 11 per cent of the total gasoline produced. The aggregate length of the gasoline pipe lines of the country is only around 4,000 miles. While this system has not attained its full development, the gasoline pipe line is economically applicable to special situations only. The pipe-line movement of gasoline is practicable only where there is a supply of gasoline in excess of near-by requirements and concentrated markets into which this supply can be moved. The longest lines developed in the Central States as a relief to the excessive refinery capacity in the Mid-Continent area. A declining price level and a rigid system of railroad charges supplied the impetus.

Similarly, the oil industry has provided its own facilities for the

movement of oil by water. The industry maintains a fleet of 750 tank ships for use on the ocean, the Great Lakes, the Mississippi River, and on canals and other waterways, representing an investment of 530 million dollars.[16] At the present time, over half of the traffic in refined products and nearly one-third of the crude-oil traffic moves in water carriers on coastwise, intercoastal, and inland waterways. In 1934, water carriers originated 803 million barrels of petroleum and its products for domestic consumption, compared with 593 million barrels originated by pipe lines, and 379 million barrels originated by rail. The first oil-carrying ship was in a sailing vessel with capacity of 7,000 barrels of crude in casks. Steel ships, carrying large tanks for the oil, were the next development and they were driven by steam. Then came the modern steel tanker, subdivided into compartments, and driven by the Diesel engine. Tankers now range in carrying capacity up to 165,000 barrels; and can dock, unload, and start on a return voyage in 24 hours. Because of automatic loading and bulk, the oil tanker represents the ultimate in transportation efficiency, exceeding that of the pipe line. In consequence the tanker draws upon the pipe line and diverts as much traffic as the geographic pattern permits. The high concentration of refining capacity in the Gulf and Atlantic coastal regions has been stimulated by the availability and cheapness of water transportation.

From the viewpoint of industrial equilibrium, the function of transportation in the petroleum industry plays a secondary role. As a service element, it does not create supply, but merely transmits it; yet it provides the means for holding the movement in some degree within established trade channels. In its integrated aspects, it helps administer the application of ratable takings in the oil fields, but its conductivity is high in respect to transferring the pressure of crude oil potentials to the markets for products.

REFINING

The refining of crude petroleum utilizes the application of heat and pressure for the separation of the raw material into its component parts and for the breakdown and recombination of the molecular structures of the derivatives. The procedure therefore involves a combination of physics, mechanics, and chemistry, and the advances in the art during the past 20 years have been radical. From an economic viewpoint, refining engages the principles of mechanization, by-product utilization, and multiple production.

The size of the refining division of the petroleum industry is de-

[16] *Nat. Petrol. News* (February 5, 1936), p. 387.

termined by the demand for its principal products and the technology available for meeting this demand. On May 23, 1936, the rated refinery capacity of the United States was 3,869,000 barrels per day, through which 2,975,000 barrels per day were being run. These figures suggest an unused capacity of 894,000 barrels per day, or 23 per cent; but the "idle" capacity is largely composed of inefficient, high-cost, obsolete units, little of which could be economically utilized to produce products of the quality in demand. Also the rated capacity of many plants tends to be larger than the over-all, working capacity. Effective refining facilities, therefore, are not now substantially in excess of requirements in terms of current and prospective demands. In fact an extensive program of refinery installations, largely of a replacement character, is under way, without which there would probably be a shortage of efficient capacity by 1937.

On January 1, 1935, there were 638 refining establishments in the United States, of which 435, representing 89 per cent of the total capacity, were operating; 196 were idle; and 7 were under construction. Of the operating plants, 15.5 per cent of their total capacity was represented by units with capacity of 100,000 barrels per day or over; 18.6 per cent, by units with capacity of 50,000 to 99,000 barrels daily; 18.5 per cent, by units of 25,000 to 49,000 barrels daily; 25.2 per cent, by units of 10,000 to 24,000 barrels daily; and 22.2 per cent, by units below 10,000 barrels daily capacity. Thus, 98 plants represented 77.7 per cent of the operating capacity of the country, while 337 plants accounted for 22.3 per cent of the capacity. It is therefore seen that the refining division of the business characteristically runs to mass production. The operating advantage of sizeable units is not caused by inherent superiorities of physical size—small refineries can be constructed with the same physical efficiency as large ones—but is a derivative of the integrative pattern that the industrial development has followed. The raw material is drawn from thousands of producing units, processed in a few hundred plants, and then distributed in the form of products through tens of thousands of outlets. The bottleneck aspect of the manufacturing function has given rise on occasion to the suggestion that the refinery is a better place for a production control than the well head where proration localizes the check on supply. During the operation of the Petroleum Code, a regulation of refinery intake was attempted as a supplementary control; but it should be observed that if proration succeeds in balancing crude oil production with the consumer demand for products, there can be no occasion for an additional barrier except for price-fixing objectives; and, moreover, the regulation of refinery throughput cannot cure the

uneconomic practices of open flow and offset drilling that are a product of the untrammelled operation of the rule of capture.

The process of refining is relatively a capital enterprise, automatic to a high degree. In 1934, for each employee engaged in this division 8,721 barrels of crude oil were processed and around $33,000 of capital were engaged. The investment in the refining division, including inventories, has been estimated at 3.4 billion dollars.[17]

Petroleum refineries are located in 33 States, but 82.9 per cent of the total operating capacity is concentrated in 8 States: Texas (25.1 per cent), California (21.0 per cent), Pennsylvania (8.2 per cent), New Jersey (7.2 per cent), Oklahoma (6.8 per cent), Indiana (5.3 per cent), Louisiana (4.8 per cent), and Kansas (4.5 per cent). In March, 1936, 38.8 per cent of the gasoline output was produced in the Atlantic and Gulf coastal region; 16.7 per cent in California; and 44.5 per cent in the interior of the country. Thus over half of our gasoline supply is manufactured in plants on deep water, reflecting the importance of tanker transportation in determining the geographic location of the industry.

The technical changes that have taken place in refining are numerous and complicated. Lack of space prevents analysis of all but three developments that have either exerted a deep impression upon the art or promise to do so as time goes on. The first of these, cracking, has revolutionized the quantity and quality of the recovery of gasoline from a barrel of crude; the second, polymerization, just getting under way, brings into view as prospective motor fuel a range of gaseous hydrocarbons now utilized for inferior purposes; the third, hydrogenation, which still awaits the proper economic setting, permits an interchangeability and flexibility in manufacturing and renders available a range of raw material extending beyond the field of petroleum.

As its name implies, cracking breaks down the heavier molecules of fuel oil and distillates into gasolines of high antiknock qualities. In 1920 the output of cracked gasoline was only 15 million barrels as compared with 101 million barrels of gasoline derived from crude oil by ordinary processes of distillation. In 1935, the production of cracked gasoline had arisen to 208 million barrels, or nearly equal in volume to the 220 million barrels of the straight-run product. Expressed in another way, cracking has enabled the recovery of gasoline from crude oil to increase from 26 per cent in 1920 to 44 per cent in 1935, and the trend of increased recovery is still upward (Fig. 11). From an economic standpoint, cracking converts a product

[17] *Nat. Petrol. News* (February 5, 1936), p. 41.

of inferior value into one of higher worth, and progress in its application has been determined by the course of price margins and developments in the technique.

Polymerization is a much newer process in its commercial application and has yet to make its impression upon the industry. Technically it is the complete reverse of cracking; it utilizes as its raw material the hydrocarbons lighter than gasoline and combines these into larger molecules of the gasoline family, in so doing also creating high antiknock quality. The raw materials now suitable for this process are waste refinery products and some of the components of natural gas,

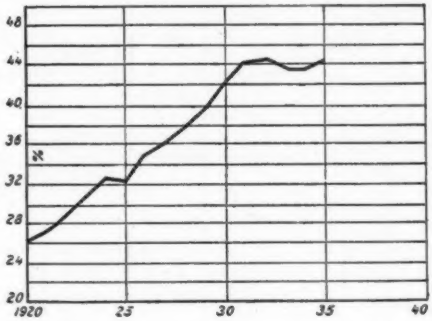

FIG. 11.—Trend of the percentage recovery of gasoline from crude oil in the United States by years, 1920–35.

such as butane and propane. Eventually the art may be expected to evolve to the point of utilizing the vastly more abundant but still lighter components of natural gas, at which time a further source of raw material will be available for the manufacture of motor fuel. For many years the natural gasoline occluded in oil-field gas has been extracted in growing degree from this material, adding materially to the output of motor fuel. For example, natural-gasoline production has increased from 9 million barrels in 1920 to 39 million barrels in 1935. With some installations already made, polymerization will contribute a small volume of gasoline in 1936 to the annual total. It has been estimated[18] that the ultimate potentialities of the process operating on both refinery and natural gases are 110 million barrels and 78 million barrels, respectively, or a total of 188 million barrels. This volume is 40 per cent of the output of motor fuel in 1935.

[18] Cook, Swanson, and Wagner, "The Thermal Process for Polymerizing Olefin-Bearing Gases," *Proc., Sixteenth Ann. Meet., Amer. Petrol. Inst.*, sec. 3, Refining (1935), p. 122.

While cracking has long enjoyed important commercial application and polymerization is undergoing initiation, hydrogenation, developed in Europe, is awaiting the stimulus of higher prices for intensive development. The process permits great flexibility in the conversion of crude oil into the products most in demand and also enables carbon compounds (coal) to be changed into hydrocarbons (oil). Costs are still too high for general application, but a moderate lift in prices, together with improvements now under way along the lines

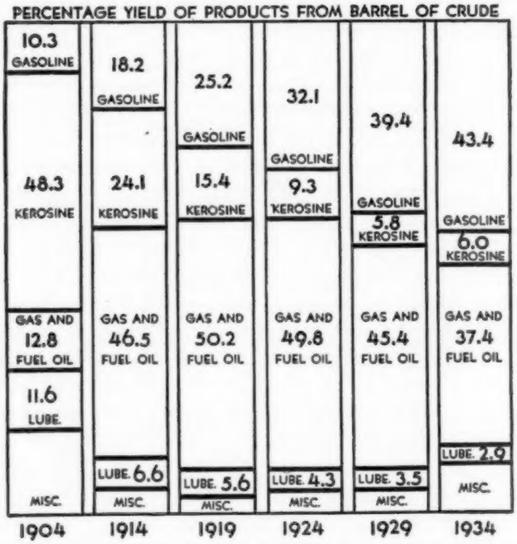

FIG. 12.—Percentage yield of principal products from crude oil by periods, 1904–34. (After *National Petroleum News*, 1936.)

of lowered costs, will create margins that will stimulate its introduction. Hydrogenation, therefore, may be regarded as a process in the offing, awaiting the arrival of economic conditions suitable to its insive development. In conjunction with cracking and polymerization, hydrogenation will ultimately be capable commercially, as it now is technically, to convert crude oil completely into motor fuel.[19] The three processes outlined promise an ample supply of motor fuel for an indefinite period.

The outstanding economic problem faced by a productive activity is the maintenance of equilibrium between supply and demand. This

[19] E. Ospina-Racines, "Economic and Technical Aspects of Polymerization," *World Petroleum* (October, 1935), p. 620.

problem presents specialized features in the case of an activity involving multiple production and a range of by-products (Fig. 12). Not only must the main product be kept in balance but sufficient flexibility must be developed so that the by-products will be carried off in trade in the proportions in which they must be manufactured. In the case of petroleum, gasoline is the main product and the other constituents are the by-products. Primary balance must be attained in respect to gasoline, but shortages or overages of other products, such as fuel oil, develop at times and create disequilibria. The mechanism by which these distortions are corrected is price, which operates to regulate demand and, through technical adaptations, to influence supply. The need of flexible prices in a by-product industry is imperative. A balance between supply and demand in respect to the main product, gasoline, is effectuated by price under freely competitive conditions, but with the operation of proration and a crude-oil quota system, this balance can be attained automatically, provided the freedom of gasoline prices is not interfered with and crude-oil quotas are based upon estimates of the consumer demand for gasoline. The crude-oil quotas suggested to the industry by the United States Bureau of Mines are computed on this principle and are far superior in workability to quotas based upon nominations of refiners, which the States used to accept as evidences of market demand. On a favorable price level, overproduction of gasoline cannot be prevented from developing, under proration, unless crude-oil supply is regulated on the basis of the consumer demand for gasoline. The refiner's demand for crude is a false criterion.

Another problem facing the refining division, with proration operating, is the resultant of a differential rigidity as between crude-oil prices and products' prices. Proration tends to result in greater stability in crude-oil prices than in products' prices, for the reason that the supply of crude oil is not always held within adequate balance

Year	*Price of Crude*	*Realization on Products*	*Refiners' Margin*
	Dollars per Barrel	*Dollars per Barrel*	*Dollars per Barrel*
1928	1.32	1.95	0.63
1929	1.36	1.99	.63
1930	1.23	1.70	.47
1931	.63	.98	.35
1932	.87	1.22	.35
1933	.62	1.06	.44
1934	1.00	1.35	.35
1935	1.00	1.53	.53

with the estimates of consumer demand for products. In consequence, price disparities tend to develop. For example, the refiners' margin, calculated on the basis of the wholesale values of the products derived from a typical barrel of Mid-Continent crude oil, has displayed the trend shown in the preceding table.

In 1930, 1932, and 1934, the refiner's margin was below his costs, despite crude-oil price levels about producing costs. The relationship, however, assumed more normal proportions in 1935. Disparities can be avoided by employing a sound quota system, such as that of the United States Bureau of Mines, and by the development of a crude-oil price structure more sensitive than it now is to changes in refining values. It is desirable, however, for disparities to develop if they are needed for a functional purpose, such as the expulsion of surplus capital from overexpanded situations or the prevention of overdevelopment.

DISTRIBUTION[20]

The marketing system of the petroleum industry is the product of economic forces operating in an environment of severe competition during a period of rapid expansion. Its development was influenced not only by the urge of a mounting supply to find the points of contact with a rising demand, but also by the desires of a widening circle of individuals to avail themselves of a new means of livelihood. The resultant is a physically efficient, highly convenient, but overdeveloped and hence high-cost mechanism. The form that the system has assumed is well adapted to its function, but its proliferation has gone to an extreme and uneconomic degree. Yet to correct this defect and rationalize the extent of the facilities would create a social problem that should be held in mind in all considerations of this subject. Without doubt gasoline could be adequately distributed without calling for the services of all the individuals now engaged in this service. But this is true of distribution in general and is not peculiar to the oil business. Hence it is perhaps not proper, without qualification, to apply purely economic criteria to a field that, in fact, not only renders a service to the consumer but contributes to the support of a vast number of individuals untrained for other pursuits.

The physical plant engaged in the distribution of gasoline is spread over the entire country and consists of specialized transportation facilities, intermediate warehouses, and retail establishments. The last named are either service stations, devoted to the sale of this commodity and related accessories, or establishments of various sorts

[20] For purposes of brevity and simplification, the discussion under this section will be limited to the distribution of gasoline.

that handle gasoline as a side line. The technical aspects of the plant in its entirety are highly proficient; the evolution in the form of equipment has been progressive, as witness the modern tank truck and electrically driven, automatic-measuring, dispensing pump; but the visual or architectural characteristics of most retailing units reflect immaturity and leave great room for improvement.

Originating at the refinery, gasoline first moves by tanker, barge, pipe line, or railroad tank car to terminals or bulk stations. The gasoline pipe line is a fairly recent adaptation of the facility long in use for moving crude oil. The oil tanker may be used interchangeably for either crude oil, gasoline, fuel oil, or even kerosene. The railroad tank car is a specialized form of freight car; barges are employed on rivers and canals. The terminal is a large depot, usually at seaboard, for receiving the product unloaded from tankers. Other terminals, seldom as large as those along the coast, are located at inland points; and these are usually serviced by pipe lines. The bulk plants are small, wayside storage stations, comprising a few tanks, a loading rack, and often a warehouse building, which are located at innumerable points within trucking distance of the retail outlets. The number of terminals and bulk plants in the country is about 20,000, having a value of $348,000,000, or $17,500 on the average.[21] From the bulk plant, gasoline is transported by tank trucks to service stations, other retail outlets, and large commercial consumers.

In 1933, the United States Bureau of the Census reported 170,404 service stations in the country. The Petroleum Administrative Board,[22] as of July 1, 1934, reported 219,382 service stations, which probably included some garages and accessory stores. It has also been estimated that there are in addition some 200,000 business places that carry gasoline and oil as a side line.[23] Of the 219,382 service stations reported, 84 per cent were non-company owned. The net book value of the company-owned service stations is given at 378 million dollars, or an average of $15,448 per station.

A simplified economic flow sheet of gasoline from refining to consumer shows four channels of distribution: the company-owned service station, the dealer who operates his own service station or retail outlet, the large consumer (such as trucking or bus companies), and the jobber. Of the total domestic consumption of gasoline, the distribution in 1935 took place approximately as follows:

[21] Petroleum Administrative Board, *Report to the Subcommittee of the Committee on Interstate and Foreign Commerce* (Washington, March 20, 1935), 31 pp.

[22] *Ibid.*, p. 9.

[23] E. B. Reeser, "Oil Marketing a Typically American Enterprise," *Nat. Petrol. News* (February 5, 1936), p. 238.

	Per Cent
Company-owned service stations	20
Dealers	40
Large consumers	15
Jobbers	15

It is thus seen that the dealer, who is in the nature of a commission agent selling the branded product of the supplying company, is a more important element in the retail business than the company-owned chains. And the trend is also toward an increasing share of the business for the dealer and a decreasing proportion for the company-owned station. The jobber is a middleman, buying the product directly from the refiner and then distributing it through his own bulk stations to chains of service stations, dealers, or large consumers, thus more or less duplicating the channels employed by the refiner in his own distribution. Practically all refining companies sell to jobbers their surplus over that flowing through the channels of their own service stations, dealers, and large-consumer outlets. Under the classification of jobbers may also be included (*a*) the so-called trackage stations, which are usually cut-price stations located at the juncture of a convenient street and a railroad siding and equipped with bulk storage for receiving tank-car deliveries; and (*b*) the oil coöperatives which buy in bulk and resell through their own retail outlets to members, who receive, in effect, a discount below the prevailing retail market, usually in the form of a "dividend."

To understand the development of this system it should be borne in mind that it is not the retail price levels, but the price differentials, or margins that have been the controlling influences. We have, therefore, to deal with four primary elements in the price structure: the wholesale price of gasoline, its retail price, the differential between the two, and the "margins" or discounts granted dealers, jobbers, and large consumers by the supply companies. The wholesale price of gasoline at the refinery is the resultant of the interaction between supply and demand in respect to the overflow above the capacity of the refining industry's own distributing system; it is therefore a sensitive, barometric price, tending to be flexible. The retail price is the price to the consumer initiated usually at the company-owned service station, and determined, on the one hand, by a differential designed to cover the company's distributing costs plus some profit, and, on the other, by the competition created by the larger volume of gasoline going through the hands of dealers and jobbers. The jobber buys at a price bearing some relationship to the spread between wholesale and retail prices; the jobber's margin at present is in the neighborhood of 5½ to 6½ cents per gallon, which must cover his costs and profit.

The dealer is automatically supplied gasoline on the basis of a margin below the retail price, now about $3\frac{1}{2}$ to 4 cents per gallon, which is usually fixed for a period and guaranteed by the supplier. The principal limiting factors in the width of this margin are the amount that exceeds the operating costs of company-owned service stations and what the dealer will keep rather than give away to his customers in an effort to increase his sales. The concessions granted large consumers by suppliers, ranging from 1 to 4 cents per gallon, are true quantity discounts, reflecting lowered costs of distribution for large deliveries and competition amongst the suppliers for this business. The retail price structure is thus ideal for the transmission of competitive forces into a low price-level, admitting little, if any, profit into the oil company distributing systems, though giving a living to a large number of individual proprietors.

The gasoline distributing system had its main development during a period of vigorous expansion in the petroleum industry and under the influence of an exceptional price era marked by credit inflation. It is important to note that from 1915 to 1930, the domestic consumption of gasoline increased from 40 million barrels to 400 million barrels, or 10-fold; and the number of motor vehicles registered, from 2.3 million to 23.1 million, likewise 10 times. Prior to the rise of automotive transportation, the oil industry was primarily a kerosene industry and it produced a system of tank-wagon delivery for this commodity. This method of distribution was ready at hand when gasoline came upon the scene. So long as the volume of gasoline was small, its sale was conducted through the same channels as kerosene. Garages, however, were soon established and provided new outlets for gasoline; the garage was the first type of dealer. As the use of the automobile expanded the oil companies seized the opportunity to set up retail establishments in the form of service stations, but at the same time continued through tank-wagon delivery to serve the garages and other types of dealers who were taking on gasoline distribution as adjuncts to their business. Later still, as the industry grew and integration proceeded, the supply of crude oil began to build up economic pressure which came more and more to seek relief in retail outlets. The oil companies did not command sufficient capital to build service stations rapidly enough; so they vied with one another to gain more and more new dealers. The dealer soon became a prize to be eagerly sought; the competition between oil companies for the dealer became increasingly severe and soon the companies were offering inducements in the form of free equipment and granting margins of increasing spread under the retail price. In this manner a vast array of dealer outlets was

established in competition with the companies' own stations. But even so the refining companies failed to expand their service station and dealer outlets fast enough to carry off the mounting supply, so the surplus was thrown on the wholesale market in tank-car lots. An opportunity was thus created for the entrance of the jobber, who purchased the marginal surplus and disposed of it in direct competition with the dealer and the company-owned service station. The maintenance of wide margins during this period of expansion, a necessity in some degree to insure the growth but nevertheless carried too far, in effect subsidized both the dealers and the jobbers and facilitated the over-development of the marketing structure with its three-way channels of distribution.[24]

Thus the overexpansion of retail outlets was the resultant of the rapid growth of a new industry during a period of credit inflation. The primary causes lying back of this development were the mounting pressure of the crude oil supply, under the impetus of the rule of capture, and the geographic expansion of market demand to all parts of the country giving opportunity to individuals to set up as proprietors of a new and expanding business. The growing integration in the oil business and the nature of the retail price structure facilitated the developments that took place. Thus the number of outlets grew more rapidly than the volume of business, with the result that the gallonage per unit declined, thereby raising costs, at the same time that the increasing competition brought about lowered selling prices. Rising costs and declining prices created the so-called marketing problem, which the Petroleum Code sought in vain to solve by intensifying one of the causes in seeking to bring about wider margins in order to reestablish a profit in this division of the business and thus prevent a contraction in the number of outlets and facilitate improved working conditions.

Viewing the dynamics of the marketing trend, there is consider-

[24] "The marketing leaders of the oil industry might possibly be criticized for their apparent short-sightedness in postponing the decline in their retail prices, thus fostering the development of a vast array of competitive marketing organizations attracted merely by the wide margins between wholesale and retail prices. Such a criticism as to the past undoubtedly is warranted; it may even be made of present conditions in several sections of the country where the economic soundness of the wide margins in effect seems questionable. In the main, however, we probably must regard the situation as the working out of economic forces in a new industry, hampered slightly perhaps by the human inability to perceive the directions and effect of those forces in the eagerness for immediate profits. It seems to be one of the ironies of most new businesses having a rapidly increasing demand, that the high rate of profit in the early stages attracts into them a rush of capital that does not cease until long after the reasonable needs of new capital, on which a fair return can be earned, have been met." Sidney Swensrud, "Distribution Problems of the Oil Industry," *Harvard Business Review* (1931), p. 399.

able evidence to suggest that the forces making for continued over-expansion in the marketing system reached a climax during the depression and are beginning to operate in a reversed direction. The change is slow and complex, but unless the situation is frozen by artificial action, a gradual movement in the direction of improved equilibrium seems probable. The reign of the rule of capture in oil production is being weakened, the trend of demand is again upward, and narrowing margins seem in the making. Contraction of margins will be facilitated by the tendency of large oil companies, under the handicap of high costs imposed by chain store taxes and other conditions, to convert their service stations into dealer outlets by leasing their facilities to individual proprietors. As this process goes further there will be less incentive to maintain margins sufficient to cover the costs of chain operators, and the highest-cost dealers will find the business less attractive. By the same token jobber margins will narrow and perhaps the role of the jobber will become less important in reflection of the opportunistic nature of his business. The process should be gradual and with sufficient growth in demand may be largely negative in its incidence—an inhibition of new expansion rather than a rapid contraction of existing facilities.

There is too much disposition to view the marketing "problem" as an isolated phenomenon. It does not rise to the dignity of a serious industrial issue except from the profit angle; it only becomes a social problem if changes become too drastic and condensed into too short a period of time. As a practical matter, a balance between crude-oil supply and consumer demand for gasoline, for the attainment of which a mechanism already exists, coupled with prices responsive to competition, is all that is needed to maintain the standards of service and to lower, but not too rapidly, the costs of distribution, with minimum disturbance to all interests concerned.

ASPECTS AS A WHOLE

We have thus far dealt with the American petroleum industry as a functioning unit in the general economy. In order to round out the treatment, it is now necessary to touch on the economic frontiers of the industry, where its operations come into contact with other interests: Foreign countries, the consumer, the State, the worker, and the investor.

The American petroleum industry has a mutuality of interest with foreign countries in two particulars: it has supplied considerable capital for the development of the oil business abroad; and it imports and exports crude oil and products in substantial volume. In its

foreign trade in oil, the United States has long had a favorable balance of trade on a dollar basis. In 1925, the net exports (exports minus imports) amounted to 365 million dollars; in 1935, to 196 million. Imports are now confined virtually to crude oil and fuel oil, while exports include also gasoline, kerosene, lubricating oils, and other products. The trend of the volume of imports and exports for recent

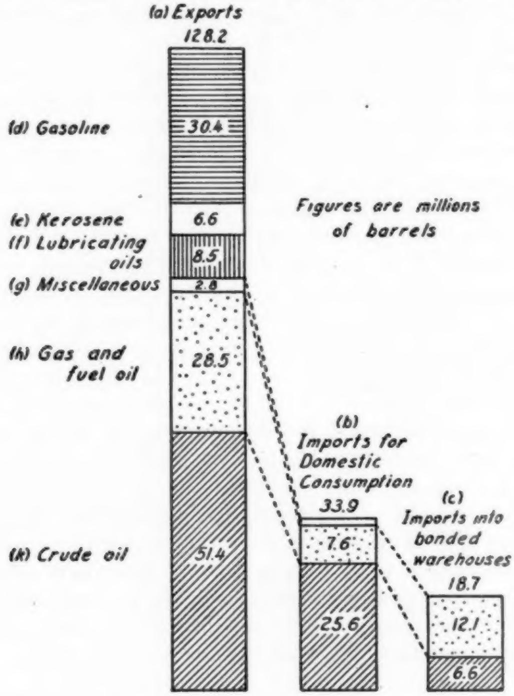

FIG. 13.—Relation of imports and exports, crude oil and its products, in 1935. (Data from U. S. Bureau of Mines.) In millions of barrels.

years is shown in Table I. In 1935 the United States imported 52.7 million barrels of crude oil and products, and exported 128.2 million barrels (Fig. 13).

Two interesting changes have taken place in the composition of our foreign trade. In the first place, imports of crude oil have declined coincidentally with an increase in the exports of crude oil. For example, in 1929 we imported 78.9 million barrels of crude oil and exported 26.4 million barrels; in 1935, the imports had dropped to

32.2 million barrels, while the exports had risen to 51.4 million. This reversal in movement has been brought about by a tariff on crude oil of 21 cents per barrel and by restrictions (under the Petroleum Code) on the volume admitted. In the second place, our imports of gasoline have declined from 8.8 million barrels in 1929 to nothing, under the imposition of a duty of 2½ cents per gallon, but exports of gasoline have likewise fallen from 62.1 million barrels in 1929 to 30.4 million barrels in 1935. In short, the imposition of trade barriers in the form of import duties has resulted in the stimulation of refining operations abroad, a loss of export business in refined products, and a reversal of our position in respect to crude oil from a net importer to a net exporter. Crude oil can be produced in Venezuela, the largest source of our imports, more cheaply than in the United States because of unit operation, hence a protective tariff tends to subsidize the less economic practices still prevalent in the oil fields of the United States. On the other hand, equity requires that if the American industry operates under a system of proration, the volume of imports shall likewise be restricted to a fair ratio to domestic production. Under the Petroleum Code, imports of oil were limited to the average rate obtaining for the second half of 1932, or 98,000 barrels daily. Imports for domestic consumption are still running at about this rate,[25] presumably as a result of a voluntary policy on the part of the importing companies, but there has developed a moderate import movement in bond for purposes of reexport. The bonded imports in 1935 totalled 18.8 million barrels, and were practically confined to crude oil and fuel oil. Our foreign-trade policy in respect to oil has been opportunistic rather than scientific, but the problems involved admittedly have not been simple. The needs of the situation require a balanced policy having regard to the principles of conservation, equity under proration, industrial equilibrium, and maximum interchange of goods in world trade.

The consumer of petroleum products is concerned with service, quality, and price. The elements of service and convenience have perhaps been overdone, but this is a less serious flaw than default in these respects. The quality of petroleum products has displayed the progressive improvement characteristic of all commodities whose technology has received the stimulus of keen competition. As to price, the situation may be examined as regards the retail price of gasoline as compared with the general-commodity price level as shown in Table III.

[25] According to the U. S. Bureau of Mines, imports of crude and products for domestic consumption averaged 93,000 barrels daily in 1935 and 88,000 barrels daily in the first 3 months of 1936.

Table III indicates that the retail price of gasoline, tax excluded, has not only displayed a downward trend for the past 12 years, but that relative to the index of all commodities it has favored the buyer. Figure 14 shows by months, over the past 4 years, the course of the prices of crude oil and its principal derivatives in relation to one another and to all commodities.

The existing relationship of the petroleum industry to the State is involved and can only be outlined in this place. The State has assumed a responsibility to the industry to aid it in the attainment and

TABLE III

Relative Price of Gasoline at Retail (Excluding Tax) in 50 Representative Cities, by Years, 1924–35

Year	*Gasoline*	*Gasoline*	*Bureau of Labor Statistics' Index of All Commodities*
	Cents per Gallon	*In Per Cent of 1926*	*In Per Cent of 1926*
1924	19.22	92.4	98.1
1925	19.94	95.9	103.5
1926	20.80	100.0	100.0
1927	17.95	86.3	95.4
1928	17.68	85.0	96.7
1929	17.72	85.2	95.3
1930	16.40	78.8	86.4
1931	12.89	62.0	73.0
1932	13.24	63.6	64.8
1933	12.75	61.3	65.9
1934	13.47	64.8	74.9
1935	13.44	64.1	80.0

maintenance of industrial equilibrium, using this term in a broad and constructive sense. This responsibility has been fulfilled, at least in part, through the instrumentality of proration, which has the support of the various State conservation commissions, the recently formed interstate compact, and the Federal Government (which renders an invaluable service through the advisory State production quotas calculated by the United States Bureau of Mines). The industry has an obligation to the State to give a good account of its stewardship and to contribute its share of taxes to the support of the Government. The industry has proven to be a fertile field for the incidence of taxation, which has been carried to considerable lengths and complexity in this business. The American Petroleum Institute estimates[26] that the total amount of taxes collected from the petroleum industry, its products and customers, in 1935 amounted to approximately $1\frac{1}{8}$

[26] *Amer. Petrol. Inst. Quar.*, Vol. 6 (1936), p. 31.

billion dollars. Reduced to a per-barrel basis, the aggregate represents \$1.14 per barrel of crude oil produced, against a weighted average price of 98 cents a barrel. About three-fourths of the total went to our State and local levies, while one-fourth was paid into the Federal Treasury. Six hundred and twenty-five million dollars, or about 56 per cent of the total, represent State gasoline taxes, and the relation of this item to the retail price of gasoline is shown in Figure 15. Gasoline taxes are approaching the point of diminishing returns and there

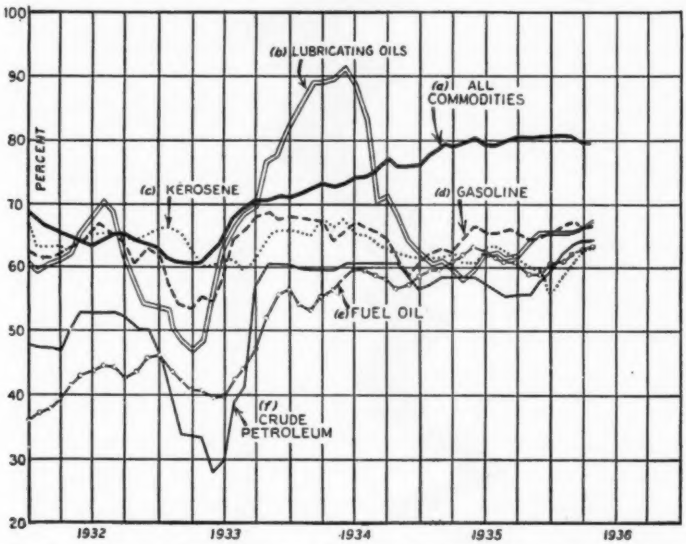

FIG. 14.—Trend of relative prices of crude oil and its products, compared with Bureau of Labor statistics index of all commodities, by months, 1932–36 (April). Average prices in 1926 = 100.

is some indication of a reversal in their expansion, or at least a cessation in their growth.

The relationship of the industry to the problems of labor have, on the whole, been marked by a considerable degree of mutually satisfactory attainment. In the producing, refining, and transportation divisions of the business, the personnel is predominately of a specialized and skilled type, located largely in the oil fields, and forming special communities of interest. The industry has provided good living conditions on the industrial frontier, where pioneering conditions exist, and the average oil camp is a striking example of convenience and even comfort in the midst, frequently, of harsh geographic

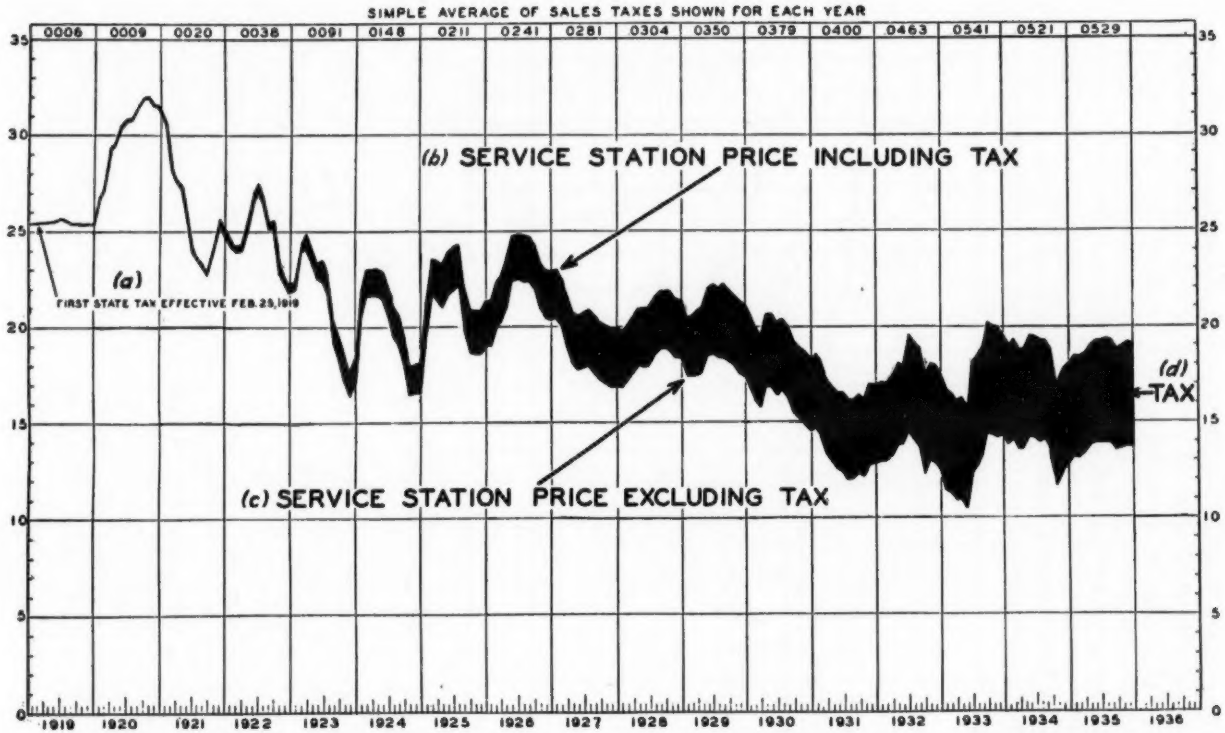

FIG. 15.—Trend of average retail price of gasoline in 50 representative cities by months, 1919–35, showing incidence of gasoline sales taxes. (Courtesy of The Texas Corporation.)

NOTE.—Federal tax of 1 cent effective June 21, 1932; additional ½ cent tax effective June 17, 1932, but withdrawn January 1, 1934.

surroundings. In the field of distribution, the nature of employment relationships has been in the direction of the growth of an independent business for thousands of individuals who have thus found a means of livelihood, or some additions to their income. The American Petroleum Institute[27] has calculated from data compiled by the United States Bureau of Labor Statistics the weekly earnings per worker in the production and refining divisions of the oil business, and the results are summarized in Table IV.

TABLE IV

AVERAGE WEEKLY EARNINGS IN THE PRODUCING AND REFINING DIVISIONS OF THE OIL BUSINESS

Hours per Week

	Averages		*Index Numbers*	
	1929 (May)	*1935 (Aug.)*	*1929 (May)*	*1935 (Aug.)*
Production	51.0	36.4	100	71
Refining	49.0	35.0	100	71
RATE PER HOUR				
Production	$0.66	$0.77	100	115
Refining	$0.64	$0.81	100	126
WEEKLY WAGES				
Production	$34.00	$27.91	100	82
Refining	$31.00	$28.07	100	91
COST OF LIVING INDEX				
	98.9	83.0	100	84
"REAL" WEEKLY WAGES*				
Production	$34.40	$33.60	100	98
Refining	$31.35	$33.80	100	108

* Actual wages divided by cost-of-living index.

The investor in the American petroleum industry has, during the past 10 to 15 years at least, received a relatively small return in earnings and dividends. Yet the rate of expansion in the size and scope of the industry has been noteworthy, indicating that the stimulus was created not so much by profits realized as the hope of profits to come. The American Petroleum Institute estimates the current investment in the petroleum industry in this country to be in the neighborhood of 12 billion dollars, compared with 11 billion in 1927, and 2 to $2\frac{3}{4}$

[27] *American Petroleum Industry* (New York, 1935), pp. 188–189.

billions in 1911.[28] The Institute also calculates, based upon reports covering about 85 per cent of the total investment, the remainder being estimated, that the average earnings for the 12-year period, 1921–32, were 1.66 per cent on the invested capital, the best year showing 4.96 per cent and 3 years marked by deficits. Standard Statistics Company,[29] has published a study of 21 oil companies, representing probably 50 to 60 per cent of the entire industry, covering the 12-year period, 1922–33. During this time the invested capital of the companies reviewed increased from 3.8 billion dollars to 7.2 billion dollars, and the ratio of reported earnings to invested capital averaged 6.1 per cent; also the cash dividends paid during this period represented a return of 4.1 per cent on the invested capital. These two figures compared, respectively, with 7.3 per cent earned and 5.6 per cent in cash return on 135 representative industrial corporations. So far as the investor is concerned, therefore, it appears that his equity has expanded but his return has been relatively small.

RÉSUMÉ

The criteria by which the competence of any industry may be judged include the ability to grow, to progress, to develop means for maintaining equilibrium, to build an efficient body of technology, and to assume a form adapted to the progressive reduction of costs. If an industry accomplishes these things or makes headway toward such objectives, and at the same time transmits the fruits of technology and lowered costs to the consuming public, then that industry may be said to have given an acceptable account of its stewardship. It is probable that no American industry has faced a more difficult series of problems in these respects than those that have confronted the oil business at every stage in its development. The requirements of a a dynamic market in fields that have changed the nature of modern industrial civilization have been imposing but have been satisfied.

[28] *American Petroleum Industry* (1935), pl. 10. The *National Petroleum News* (February 5, 1936), p. 41, estimates the investment as follows:

Item	*Million Dollars*
Producing properties	5,665
Natural gasoline plants	270
Oil pipe lines	941
Refineries	3,400
Marketing facilities	
Bulk stations	432
Service stations	1,228
Gasoline pipe lines	65
Trucks	375
Tank cars	216
Tank vessels	530
Miscellaneous	154
Total, all properties	13,276

[29] S. N. Shaw, "Two Cycles of Corporation Profits: Sec. 6," *The Oil Industry* (New York, 1936). 80 pp.

A brilliant body of technology has been constructed to meet the specialized requirements of every department of the undertaking, and vistas are opening up of continuing advancement in new and ingenious directions. The problems of equilibrium have been intricate and at times apparently insoluble, because of the handicaps imposed by the rule of capture; and yet a new mechanism has been evolved by the industry, with the coöperation of the oil-producing States and the Federal Government, which has made headway in meeting even this difficult and obdurate issue. The economic structure of the industry has adapted itself to the requirements of lessening costs, with a resultant reflection in price, so that the consumption of petroleum products has never been retarded by undue claims upon the existing purchasing power of the public.

The American petroleum industry has been charged with a wasteful development of the resource. The requirements of rapid expansion and the rule of capture have been responsible for relatively heavy field losses in the production of crude petroleum, but improved technology and proration have reduced their incidence as well as created offsetting economies. There are still flagrant examples of inefficiencies arising from hasty withdrawals; but, however spectacular when viewed singly, they no longer bulk large in the aggregate, and are subject to correction by the stricter enforcement of the State conservation laws and the more rigid application of the principle of ratable takings. The technical knowledge relating to the utilization of reservoir energy, gained in recent years under the restricted flow imposed by proration, has revolutionized the production concept, and grossly wasteful production practices are coming to be limited to residual situations where legal technicalities or political laxity are invoked in their favor. The ideal application of optimum methods, however, waits upon the further nullification of the rule of capture, either through the constructive evolution of the proration mechanism, or else as a result of the foreshortening of the process through direct elimination of the capture principle.

The problem of economic equilibrium in the petroleum industry in the interim is not wholly solved. The proration mechanism has not yet been perfected, either in structure or in application. It can be impaired if price fixing is permitted to enter into its operation, for the existence of a flexible price structure is essential to its adequate development. Its administration needs to be developed so that unnecessary wells are not required under its rulings and the rate of drilling may be accorded bilateral flexibility in responding to economic influences. The State production quotas provided by the United States Bureau of

Mines deserve readier acceptance by the State conservation commissions, and the distinction between a crude-oil quota balanced against refiners' demand and one equated to the consumer's demand for products requires a clear perception on the part of all those interested in equilibrium. Nevertheless, a pragmatic, flexible plan of action has been in course of evolution for a period of 10 years, and the essential framework of a workable operating structure has already been established.

The oil business in the United States is the first great industry to develop a new method of conducting its business, having altered the design of its economic structure in order to make the enterprise more susceptible to regulation by the ordinary laws of economics and to free it from the disturbing influences of the unchecked operation of the rule of capture. The industry is experimenting with a new economic form. The further evolution of proration will afford a fascinating case history of an effort by competitive enterprise, with our existing legal background, to find a practical solution for a complicated problem of unique character. Much progress has already been registered toward a workable answer. The undertaking deserves the interested attention of all concerned.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 197-211

INTERRELATIONSHIP OF GEOLOGY AND GEOPHYSICS[1]

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ABSTRACT

Geophysics has advanced to such an important place in the field of structural prospecting that there is a tendency, in some quarters, to relegate the geologist to a position of secondary importance in this field. Geophysics is here regarded as purely a new and complex means of reading strike and dip and, as such, is to be classed as an additional geologic tool.

Geology serves as an indispensable guide to every step of geophysical activity, and without such guidance, the geophysicist can not hope to reach his objective. Lack of coördination between the two technical branches has led, in the past, to much misinterpretation of geophysics and continued future success will depend upon a greater degree of coöperation in preparing the background for geophysical prospecting and in interpreting the results obtained by such methods.

INTRODUCTION

The recent phenomenal development of geophysics as a factor in the search for new oil reserves leads to the following questions. Is the petroleum geologist, in that particular department of his work that deals with structural prospecting, to take a position of secondary importance to the geophysicist, or is geophysics to be regarded as another tool, which the geologist may utilize to solve his problems more effectively? These questions are brought to mind by the apparent present-day tendency of geophysics to dominate, in certain provinces, the field of oil finding.

In a review of the new fields found during the past few years, it is impressive to note the widespread discovery claims of the geophysicist. The geologist, regardless of the degree of his participation, is seldom mentioned nor is the application of the principles of geology outwardly credited with having been an important factor in bringing about these successes. The uninformed observer, and this class may be said to include many men active in petroleum exploration, may arrive at the conclusion from this that in the search for new petroleum supplies, geologists have been definitely relegated, in many areas, to

[1] Manuscript received, January 16, 1937.

[2] Consulting geologist, 813 Second National Building. The writer wishes to acknowledge a debt of gratitude to the numerous geologists and geophysicists who have assisted in the preparation of this paper by their advice and criticism. Those who have been particularly helpful include Joseph L. Adler and L. C. Snider of New York, Paul Weaver of Houston, and C. L. Moody of Shreveport.

a position decidedly secondary in importance to geophysicists. It is the purpose of the writer to consider the function of these two groups and to analyze their relationship.

TECHNIQUE OF STRUCTURAL PROSPECTING

In the early days of petroleum geology, the search for oil and gas was mainly confined to regions in which consolidated rocks permitted a relatively simple structural interpretation through a study of surface formations. During a period of intensive study covering approximately 30 years, practically all of the more obvious uplifts have been mapped and tested by the drill. Early in this period, structural study was carried beneath the surface by means of well logs and a knowledge of general structural conditions has thus been extended into areas where poor exposures and unconsolidated sediments constitute a handicap to surface mapping. In certain areas where stratigraphic conditions justify, the acquisition of subsurface information has been augmented by use of the core drill, but normally, where well control is scattered, prospecting has been guided too frequently by insufficient structural information.

The progress of the technique of structural prospecting has followed a more or less orderly sequence. Structural study and subsequent drilling and discovery have begun with the obvious type of trap and have progressed to the obscure type, with new methods of solution being developed as necessity dictated. When the anticlinal theory first gained a wide following, the search for structures was confined to simple types that would fit a simplified theory. The complexity of structural forms under which oil and gas may accumulate was not recognized until this wide diversity was brought to light in the natural progress of oil-field development.

With the gradual elimination of obvious structures in areas in which preliminary surface and subsurface study is possible, the necessity arose for a method by which deep-seated structural conditions could be appraised in the absence of surficial criteria. This necessity was met by the adaptation of known geophysical methods to this purpose. The first geophysical instruments to be put into use were the torsion balance, the magnetometer, and the refraction seismograph, followed more recently by the reflection seismograph.

INTRODUCTION OF GEOPHYSICS

The Gulf Coast area has constituted the proving ground for geophysical methods. The torsion balance and the refraction seismograph, aiming directly toward the detection of the salt core that lies

beneath the arched sediments of the typical salt dome, were introduced because it was obvious to the geophysicist and seismologist that they should have a capacity for isolating such salt masses. During the first few years of operation, the effectiveness of these methods was such that virtually all of the shallow, piercement type domes were located, together with several domes in which the intruded salt mass lay at greater depths. Their effectiveness, however, decreases rapidly with depth, due to the increased generalization in the character of the records; and the reflection seismograph, which does not incorporate this limitation to as marked a degree, was introduced and took the lead in the field of geophysical exploration.

After such a successful introduction on the Gulf Coast, the use of geophysics was extended out into other regions. The refraction seismograph was found to be a successful detector of arched sediments in areas where massive hard members occur in the section and the torsion balance, under similar conditions, was used with fair success. The torsion balance, despite its limitations, continues to occupy an important place on the Gulf Coast as a reconnaissance instrument. It has the advantage of speed and economy and it has furnished a background that has pointed to many domes that have subsequently been detailed by reflections. The reflection seismograph, however, has an adaptability that the other instruments lack, and it is being operated, with varying success, wherever petroleum exploration is being prosecuted on a large scale. In the absence of detailed surface or subsurface geology, it is considered the final appraiser of structural conditions and it is applied as a final check against both the refraction seismograph and torsion balance, before development is commenced.

Of the geophysical methods discussed, the data to be derived from the records of the reflection seismograph more nearly approximate actual structural elements than do those furnished by the other two. An anomaly discovered by the torsion balance can not, without additional information produced by other means, be attributed to any unique geological structure. The anomaly merely indicates that a body, differing notably in specific gravity from the surrounding rocks, lies somewhere near, below the site of the anomaly, or that, if the body be a stratum, it is thicker or thinner, shallower or deeper, at that point than normally. The intensity and shape of the anomaly are functions of the relative specific gravity, depth, size, and shape of the structural body which causes it, and because these four variables can not be determined individually with the torsion balance, but only their sum total effect, unsupplemented torsion-balance data can be converted into structural terms only empirically by comparison with

similar anomalies in the same region, the structural source of which is known.

Similarly with the refraction seismograph, even under the most favorable circumstances, only the velocity with which sound waves are propagated in hard beds can be determined. If there are several hard beds, successively deeper, it is usually true that the mapping of dip and strike, and the determination of faulting, can be done by the refraction method, only as to the shallowest of these, and only in special cases can similar information be obtained of the deeper hard beds.

It is also a limitation of this method that the distance between shot-point and recorder on the surface is large compared with the depth of the hard bed being mapped, usually four times as a minimum. This means a much greater expense than for the reflection seismograph, and also means that errors in computation are introduced if there are variations in the velocity of the beds above the hard one being mapped. While correct conclusions can frequently be inferred from the velocities measured, as to the nature of the rock bodies and the depths of the contacts between them, it is obvious from the foregoing relationship that the refraction seismograph is not a sufficiently delicate tool for the detection of deep-seated oil-bearing structures. The reflection seismograph, on the other hand, determines directly the structural attitude of the arched sediments that comprise the uplifted area over distances as short as may be desired, and regardless of whether correlation or slope method is being applied, the results need no conversion in order to be directly utilized for structural interpretative purposes. That is true in the same sense as are the points on the correlating datum established by the subsurface geologist from a study of well logs or the dips recorded in the field by the reconnaissance geologist.

SUMMARY OF GEOPHYSICAL METHODS

TORSION BALANCE AND REFRACTION SEISMOGRAPH

This paper is written from the viewpoint of the geologist, and the discussion of the basic principles of geophysical methods has been carried only so far as is necessary to clarify the relationship that is under discussion. The particular manner in which the principles of geology are directly applicable to the interpretation of geophysics varies with the type of instrument in use. The torsion-balance operator deals with abstract physical factors and in the presence of a gravitational anomaly he does not say, "here is a structure," but rather, "here is evidence of gravitational irregularity that may be due to

structure." The results of such surveys when placed on the map, are not intended to convey a direct structural message, but, as has already been said, they may be compared with other anomalies, in the same region, whose structural source is already known, for an establishment of indirect structural valuation. In a similar sense, the refraction seismograph, in recording the time required for sound to travel between certain points through the earth's crust, registers any radical change in the rate of speed that would indicate a variation in the composition of the conveying medium along the path of the sound wave. This may, in turn, signify the presence of salt or of arched sediments, according to the character of the record. In borderline cases, that is, in cases of only slight refraction "leads," and in cases of deeply penetrating shots, there is always the possibility that the higher velocity may result merely from the compaction of the sediments due to structure building and that such structures may be anticlines, synclines, fault zones, or even mere monoclines of steeper than normal dip. In any event, the inference that abnormally high velocities necessarily indicate favorable structure can not be drawn without first having appraised all of the numerous geologic factors that have a direct bearing on the problem.

REFLECTION SEISMOGRAPH

Correlation method.—The contributions of the geologist form an indispensable background to the proper interpretation of torsion balance and refraction seismic data and he assumes a rôle of even greater importance in connection with the reflection seismograph. This instrument operates by passing a sound pulse, created by a dynamite explosion, into the earth and recording the time in which it is reflected back to the surface. The reflecting media are certain surfaces contained within the deeply buried stratigraphic section. It is apparent from this that stratigraphy enters the problem as a basic factor, since the capacity of certain parts of the lithologic section to act as consistent reflectors constitutes the gauge of the value of the resulting records. If the subsurface section is made up of alternating hard and soft members in which definite characteristics of lithologic nature and hardness persist laterally for considerable distances, then it is possible to employ the correlation method of shooting. Under these circumstances and by this method, certain groups of beds that may be referred to as reflecting constants, are recordable throughout broad areas, and, by reducing time records to feet, depths to such datum horizons may be placed on the map and contoured as in ordinary subsurface mapping. In the absence of the particular lithologic type

that is basicly essential to correlation shooting, the slope method is employed.

Slope method.—The sediments that comprise some of the thicker segments of the stratigraphic column, were laid down under shoreline conditions where rapid advances and retreats of the sea and strong and irregular cross-currents resulted in the continual reworking of materials in the processes of deposition. These depositional influences have produced a section in which but few members maintain a lateral lithologic unity. Such is the character of most of the later Tertiary sediments of the Gulf Coast. In parts of this region, as well as in other regions of similar type, the variable lithologic character is, in most places, an effective barrier to the use of the correlation method. In its place, the slope method has been perfected and is in general use and, though the results to be obtained with slopes are much less satisfactory than with correlations, the method is being used very effectively to outline, in a general way, numerous favorable structural areas.

When slope shooting is employed, each shot-point, with its detector system, furnishes a record that is, in theory, a localized unit in the system of structural control. This is true because the reflecting beds may be scattered throughout a vertical section with a thickness of 10,000 feet or more and it is improbable that any unit group of beds will consistently record from one station to another. Upon occasions, a datum group may be followed through certain portions of a limited survey, but in localities where it has been found necessary definitely to discard correlations in favor of slopes, this is not always to be anticipated.

Upon completion of such a survey, the preferred practice is to construct slope profiles covering each independent traverse. These profiles present a balanced picture of slope conditions and permit an appraisal of localized conflicts that tend to confuse structural interpretation. As a second step, the slopes are placed on the map, with definite footage values assigned to the distance covered by the individual reading. These latter data make it possible to accomplish a direct reduction from recorded slopes to structural contours. In this reduction process, it is obviously difficult, in the absence of a common correlating medium, to tie the various traverses together, but this does not constitute an important handicap except in the presence of major faulting.

Delimitation of faulting.—In areas characterized by complex fault patterns, recognition and delimitation of faults is not ordinarily difficult where correlations may be employed. If one or more groups of

datum beds are present throughout a detailed survey, faults may, under some conditions, be rather accurately mapped, both as to position and as to amount of displacement. The situation described is, of course, a more or less ideal one. It is true, nevertheless, that a correlation survey may be fairly accurate in this department, under favorable circumstances. With slopes, however, faults constitute one of the most difficult phases of interpretation. This difficulty is easily understood when it is pointed out that in the records of a given profile, only chance reflectors may record at random throughout 5,000–10,000 feet of vertical section and, in an almost complete absence of a common datum through which vertical orientation may be accomplished, one or more faults may exist without leaving sufficient evidence of displacement to afford recognition. There are known instances, in fact, where traverses, exhibiting relatively flat, irregular slopes, have crossed faults with displacements in excess of 500 feet, without affording critical evidence of such features.

STRATIGRAPHIC ASPECTS

It has been pointed out that in the operation of the seismograph, the velocity of the sound pulse varies with the character of the medium through which it travels. Thus, sound travels through compact shale with higher velocities than through porous sand. Heavy, porous limestone, such as coquina, conveys sound with relatively low velocities, whereas limestone that is tightly cemented ordinarily serves as a high velocity conductor.

Since the velocity of sound is the basis of measurement with the seismograph and since such velocities are variable in keeping with the lithologic medium through which they travel, changes in velocity due to unanticipated changes in the composition of the stratigraphic section may introduce errors in calculating relative depths to significant reflecting horizons. A good example of this effect is found at Smackover, Arkansas. In this field, the sands within the productive zone grade from a thick, relatively pure sand phase on the crest of the dome to shales off the flanks. Theoretically, since the velocity of shales is somewhat higher than that of sands, a seismic survey of this dome, without proper correction for such lithologic change, might furnish a structural conception to be interpreted as a depression instead of an uplift.

Increased velocities that result from lateral changes in lithologic character are ordinarily observable in domal areas on the Gulf Coast and in structural areas elsewhere. They are observed to occur along seismic lines that penetrate areas of folded rocks and may arise from

the compaction produced by localized structural movement. Without proper correction, these increases tend toward a false accentuation of the degree of structural dip.

Under shore-line conditions, there is normally a depositional change from shallow-water deposits along the inner margin of deposition, to deep-water deposits away from this margin, and the direction of the lines along which such orderly changes in facies occur is predictable as a result of a paleogeographic study of the region. Such gradations in lithologic type introduce rather pronounced changes in average velocities in certain districts. Considered from a regional standpoint, these changes are more or less gradual and regular, but locally, limestone stringers or other hard members may be introduced and these can result in records that may lead to erroneous conclusions within the localized survey. This is particularly true under conditions where sand stringers or highly lenticular sand zones have been developed parallel with old shore lines. In places a change in lithologic facies along the updip margin of a regional structure may be such as to furnish high speeds that obliterate existing subsidiary anticlinal closure from the records. It is true, of course, that the effects here described constitute a more important factor in areas of minor closure than in those of major closure.

In many areas, there takes place a regional wedging of prominent stratigraphic units that produces the type of influence that is under discussion. Such changes exist in the Comanche series on the flanks of the Sabine uplift. In a given section, there may be a lateral wedging-out of a low-speed segment, accompanied by a wedging-in of a high-speed segment. Such a lateral shift in the composition balance of the section tends to changes in velocity so that an actual regional steepening of dip might be interpreted as a pronounced regional flattening.

If proper allowance is not made for their presence, major unconformities may also be a factor in changing velocities and can result in radical misconceptions as to the significance of geophysical data. Such unconformities may also produce stratigraphic pinch-outs, but the convergence of reflectors that would indicate the presence of such phenomena may or may not be subject to proper interpretation in the absence of a detailed knowledge of stratigraphy.

The foregoing illustrations are only a few of those that might be cited to show the important influences exerted by stratigraphic change on the interpretation of geophysical investigation. These statements might be amplified further but it is probable that additional material would serve little purpose in clarifying the issues under consideration.

REGIONAL STRUCTURAL ASPECTS

The function of the geologist in relation to the solution of structural problems begins first with a consideration of the regional structure. It is a matter of common geological knowledge that, throughout most of the petroliferous provinces of the country, folds and faults that are the product of regional crustal adjustments tend to arrange themselves, in their relation to one another, into more or less regular patterns. The character of such patterns varies between provinces, according to the local alignment of the major features that control crustal movements. Thus, in intermontane areas and along mountainous coast lines, structures characteristically occur along lines that are directly related to the axes of the mountains: in major basins, structures occupy trends that are established in conjunction with major lines of weakness in the basement rocks. In the Balcones fault system, which extends across the state of Texas for a distance of 500 miles, the main zone of fracturing occupies a line that nearly parallels the old coast line and the individual faults, lying *en échelon*, parallel one another at small angles to the line of direction of the zone. Such an arrangement is also characteristic of fault systems in other regions. The recognition of the influence of such regional effects upon structural arrangement is important, especially in its bearing upon structural interpretation. In the territory included within their zone of influence, these regional movements have an important bearing upon the relationship of one structure to another and upon the axial orientation of the structures themselves.

In the salt-dome areas of the Gulf Coast and of the regions surrounding the Sabine uplift, no such characteristic regional arrangement of structures is readily discernible. The structures that typify these areas have resulted from the upward movement of salt plugs arising presumably from deeply buried salt masses and this movement, which may have been brought about through the action of crustal adjustments, is not thoroughly understood. Complex fault patterns characterize a great many of these salt structures, particularly those that affect the young sediments of the Gulf Coast proper. These faults are localized within the immediate area of uplift and are the result of the intensive upthrusting action of the salt, with no direct relationship to regional influences. It is true that in the southwestern part of the immediate coastal region, there is evidence of a major line of weakness that parallels the coast line, along which occurs a trend arrangement of structures that may have resulted from salt action along a regional fault system. In addition, there is evidence in other localities of the

coastal region of Texas and Louisiana that regional faults may have influenced the pattern of structural development. With our present limited knowledge, however, such instances may not be considered typical of coastal conditions.

LOCAL STRUCTURAL ASPECTS

Just as the structures that are the product of regional movement ordinarily occur in a relationship to one another that is generally predictable, so do individual structures assume forms that are characteristic of the local phase of the regional forces that have produced them. This statement is, of course, a generalization and is intended to convey the idea that in any given region, structures are the product of forces that tend to produce, locally, a certain type of fold. Illustrations that follow have been selected from areas with which the writer is most familiar. In intermontane areas, for example, some of the folds occur along trends, paralleling the axes of the mountains. Also, the individual folds within such trends incorporate features that show a general degree of structural uniformity. This uniformity may apply to axial direction, general form, degree of symmetry, and direction of faulting.

Similar statements may be made in regard to fault traps, particularly those along regional fault zones. The traps formed as a part of the Balcones system are essentially of the same type, even though they may differ considerably in detail. Thus, a thorough knowledge of the regional structural conditions surrounding such occurrences permits an advance conception of such features as the form of trap and direction and approximate degree of hade of faulting of any particular locality.

In the Permian basin area of West Texas and New Mexico, traps that serve to accumulate oil and gas may be classified in one of two or three distinct types. On the west side of the central platform, such traps have been formed by a combination of folding and deposition. They occur along well developed trends and their essential physical characteristics may be anticipated in advance of drilling. Within the platform area, folds assume, in the main, an orderly arrangement along regional lines. In individual detail, these folds are similar to one another, with the same directional assymetry and with a predictable axial orientation.

There is no intention to convey the idea that all structures in the Permian basin, or in any other province, show a similarity in their individual characteristics, but merely that a sufficient number of them display a uniformity of development and relationship to create

an outstanding type that reflects the forces that have been responsible for their development.

In the Gulf coastal region, the statements already made as to the interrelationship of structures may not so generally be applied. In the Laredo district of southwest Texas, oil and gas traps are largely products of deposition, although faulting may have constituted an important factor in some places. In the area adjacent to the coast, between Hidalgo and Jackson counties, structures do assume a trend arrangement and uplifts such as Saxet, Refugio, and Greta are the outstanding type for this locality. Associated with these type structures, there are fault traps that occupy a separate trend inland from the Refugio line of folding and, coastward, there are additional lines along which either typical folds or typical faults may occur. Under either condition, such structures are found to be limited to a very narrow group of types and to bear to one another a relationship that is characteristic of the region in which they occur.

Eastward along the coast, in the typical salt-dome regions of Texas and Louisiana, a background of structural knowledge is particularly valuable in solving the problems of advance structural interpretation. An effort has been made in the past to work out a regional structural pattern that would explain the interrelationship of domes. There has been a prevalent idea that domes have developed along lines of weakness that have resulted from regional adjustments but little concrete evidence has been advanced to indicate that such lines are of an orderly, predictable nature.

Although it is probable that the pattern of occurrence of coastal domes is a haphazard one, individual domes have a sufficient similarity one to another that they may be placed in a rather restricted group of types. Thus, piercement domes may be considered occupants of one class, in the sense that they are more or less of the same form. They may vary in size, in the degree of dip of the flanks and in the presence or absence of overhang but they all possess a more or less circular symmetry and their individual variations from type are only secondary to the preponderant similarities that characterize them.

An increase in the individuality of structural types becomes apparent when a study of deep-seated domes is undertaken. Here again, there is a large group, the members of which are somewhat uniform in structural form but in which individual characteristics are more pronounced. These domes, of which Hastings, Iowa, and Anahuac may be chosen as examples, are circular and are, in a sense, all of the same type, except for their fault patterns. As a matter of fact, it may

be said that the fundamental domal form is normally altered solely through the agency of faulting. Such faulting is present, in varying degrees, in all deep-seated domes and it may take the form of simple faults, or of upthrown or downthrown blocks. Many domes are cut by a central graben with an axis at right angles to the major axis of the dome and by additional radial faults or radial grabens.

The intensity of fault movement may produce domes with little or with great distortion. Central grabens are known to have developed to such an extent that two widely separated productive areas occur on opposite sides of the dome. In such cases, the outlines of the uplifted area give the appearance of an axial anticline, rather than a dome. Where the central graben is of minor development, both as to width and displacement of the block, there is little distortion in the form of the dome and no interruption to the distribution of production.

Besides the class of deep-seated domes here described, there is another class in which each member constitutes a separate structural problem. In this group, the uplifted area incorporates few of the structural features that have come to be recognized in connection with salt domes. Some of these traps consist of areas of minor closure on the downthrown side of faults. Others are structural noses in which updip closure may be affected by lensing or by faulting. In still others, the area of closure may be formed by a series of faults in which blocks may be barren or productive without exact relationship to structural position.

It is unquestionably true that in most provinces in which active structural study is in progress, regional forces that are recognizable have been mainly responsible for the structures that are the object of search and an understanding of these forces and of the folds that are characteristically produced by them is a prime requisite to the interpretation of the results of further geological and geophysical exploration. On the Gulf Coast, in particular, the individual structure, in the absence of a recognized pattern of domal interrelationship, has certain features that are representative of the group and a thorough understanding of these characteristics is an indispensable aid to the interpretation of the data obtained by exploration. A knowledge of all of these fundamentals of regional and local structural occurrence constitutes the important working tool of the structural geologist.

SIGNIFICANCE OF STRUCTURAL ELEMENTS AS RELATED TO SOURCE

The structural elements which, grouped together, describe a fold are in themselves of uniform, simple character but the pattern produced by their interrelations may be of extreme complexity. Strictly

from a structural standpoint, a short unit section of inclined strata, considered individually, is a positive element that is not subject to interpretation, but a large number of such units, grouped together, may afford an opportunity for numerous interpretations.

The unit itself is the basis of a structural survey, and, regardless of the means of acquisition of knowledge concerning it, its character and significance remain constant. A dip reading taken on a unit of strata at the surface differs in no important degree from a slope sketched on a seismic record or a section of datum horizon indicated by correlation of two adjacent well logs. In other words, the character of the record from which structural data are derived may differ radically, but each acceptable record should have the capacity to convey the same type of basic information.

In a study of this nature, these units are under consideration for the structural information they may convey but each is, in reality, a stratigraphic record and as such, is subject to geologic appraisal as regards fitness to serve as an element in structural analysis. An inclined surface bed may be the product of cross-bedding or slumping; fossil horizons that are the basis of well-log correlations may have varying degrees of reliability; and slopes derived from seismic records may be in conflict with known stratigraphic conditions; therefore, in evaluating these elements, the geological background becomes a prime requisite long before a structural study has reached the stage of actual structural interpretation.

There is a current notion in some quarters that the elements that form the basis for structural study take on a new and strange significance when the information source is the reflection seismograph. It is true that the results may be more than ordinarily significant because they have been obtained in areas where other sources of structural information have failed, but from a purely technical viewpoint, there is nothing new in type nor is there release from the limitations that characteristically surround such data. It would seem, then, essentially fallacious to contend for the existence of a distinct dividing line between orthodox structural geology and geophysics, or to assume that geophysics is a completely integrated science that has brought a new set of fundamentals, other than mechanical, into the realm of structural prospecting.

FUNCTION OF THE GEOLOGIST IN GEOPHYSICAL PROSPECTING

The geologist may be said to have both a primary and a secondary function in his relation to structural geology. The primary function consists in acquiring a detailed knowledge of regional and local stra-

tigraphy, since it is from this basis that the ground work for structural prospecting is laid. The secondary function is that of reducing geologic data to structural terms. A structural problem can be solved only by resolving it to its component parts. The process of building these parts back into a picture that is not in conflict with recognized controlling structural elements is a step that is accomplished with no material change in the objective or in the character of the end product, regardless of whether the resolving process has been effected by surface, subsurface, or geophysical means. In any event, each group of elements falls more or less within the same category of usefulness.

There was a time when most geophysicists and not a few geologists regarded geophysics as the cure-all for the problems of structural prospecting, but a readjustment of values has taken place and this idea is not so prevalent. It is true that in many areas where the geologist has set up the essential, preliminary geologic background, the geophysicist has appeared to reap all the glory by presenting evidence of localized structure and this has fostered a tendency on the part of the geologist to retire to the background and permit the geophysicist to make localized, purely mechanical interpretations of the results of his studies. This lack of continuous coöperation between the two has led to much needless misinterpretation of geophysics and there is a rapidly growing recognition of the error of this attitude. There are indications, in areas subjected to thorough prospecting, that the days of easy, successful accomplishment for geophysical methods are passing and this change is, in part, being effected by the gradual elimination of old prospects that have resulted from decades of comprehensive geologic study. Continued success in solving the complex structural problems that will unquestionably typify the future, therefore, will depend on greater improvements in technique and a guidance that is based on a more intensive application of geologic principles.

CONCLUSIONS

This paper might be expanded to much greater length by a further recital of proofs of the interdependence of geology and geophysics. It might be said with truth that geophysics has added greatly to the depth of geologic thought because it has given to the geologist a means of stratigraphic and structural appraisal that was formerly denied him. It might also be stated that geology serves as a guide to every step of geophysical activity, and, that without such guidance the geophysicist can not hope to reach his objective. Sufficient space has been devoted to this phase of the subject, however, to have clarified the question of this relationship.

In order that both geologist and geophysicist may benefit most effectively, the following suggestions are summarized.

1. *That the general direction of any oil-prospecting campaign be placed in charge of a competent geologist.* The obvious advantage of this arrangement is that, in laying out the areas to be prospected, full advantage may be taken of all the accumulated geologic knowledge, both in its bearing on the character of the records to be anticipated and on structural interpretation.

2. *That each geophysical field party should be accompanied by a competent field geologist.* This individual may guide the work from day to day and thus take full advantage of available geologic information. One of his important duties should consist of seeing that sufficient work is done where needed to avoid resurveying and in preventing needless work in areas that have no bearing on the particular problem.

3. *That an office geologist be detailed to work side-by-side with the geophysicist who makes interpretative maps.* The combination of training and experience in both geophysically applied physics and applied geology will produce results that will be devoid of many of the obvious errors that have characterized much of the unguided geophysics of the past.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 212-232, 3 FIGS.

STRUCTURE OF SOUTHEASTERN PART OF TEJON QUADRANGLE, CALIFORNIA[1]

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ABSTRACT

The southeastern part of the Tejon Quadrangle, California, is of interest to economic geologists for the light its history may throw upon that of near-by oil-producing and potentially productive regions. The rocks are both crystalline and sedimentary; the sediments, of Tertiary and Quaternary age, aggregate more than 30,000 feet in thickness.

Faulting is the dominant structural feature. The area is divided into three structural units by the Clearwater and the Palomas Canyon faults. The Clearwater fault has had a complex history, both vertical and horizontal movements having occurred at widely separated times. The Palomas Canyon fault shows evidence of vertical displacement only. Other faults of the region are the Violin Canyon, the San Francisquito, the Bee Canyon, and the Whitaker.

Folds observed are the Castaic syncline, the Agua Blanca overturn, and the Elizabeth Lake Canyon upwarp. In addition, numerous small unnamed anticlines and synclines have been mapped.

INTRODUCTION

The Tejon Quadrangle, which lies between Latitude 34° 30′ and 35° N., and Longitude 118° 30′ and 119° W., occupies a strategic position geologically in southern California. It is an area of integrated marine and nonmarine Tertiary sediments forming the boundary between the Santa Ynez-San Rafael ranges on the west and the granitic masses that form the margin of the Mohave Desert on the east. Lying as it does between the Santa Ynez overfolds and the San Andreas shear zone, it partakes structurally somewhat of the nature of both.

The area mapped of itself holds little promise of large production of oil, in spite of the fact that it borders the richly productive Ventura basin farther south and west. Nevertheless, its stratigraphy and structure are of great interest to the economic geologist. Exploration for oil in California has passed the simple anticline-hunting stage and now requires an intensive study of the regional geology. The history of this marginal area may throw light upon the history of several producing and potential oil structures.

The area described in this paper is rectangular and comprises approximately 200 square miles in the southeastern part of the quad-

[1] Manuscript received, October 16, 1936.

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rangle. Its east and south boundaries coincide with the respective boundaries of the quadrangle as a whole, and it extends west approximately to Longitude 118° 50′ W. and north nearly to Latitude 34° 40′ N., being about 18 miles east and west and 11 miles north and south. It lies almost entirely in Los Angeles County, only a few square miles of its westernmost part extending into Ventura County.

The south boundary of the Tejon Quadrangle is about 45 miles north of the city of Los Angeles, and the part herein described is most easily reached by the inland route to San Francisco, commonly known as the Ridge Route (United States Highway 99), which divides the area into almost equal parts. There are few other good roads in the district. As a whole it is comparatively rough and inaccessible.

The writer wishes to express his sincere appreciation for the help of J. P. Buwalda and other members of the staff of the California Institute of Technology. He is particularly indebted to W. S. W. Kew of the Standard Oil Company of California and to R. D. Reed of The Texas Company for their encouragement, advice, and criticism in the field.

STRATIGRAPHY

CRYSTALLINE COMPLEX

Crystalline rocks crop out in various parts of the area. They are igneous and metamorphic, and formed the highlands from which the later Tertiary sediments were derived, and the basement upon which they were deposited. They likewise have been the buttresses against which the weaker sediments have been folded and crushed.

Probably the oldest rocks are the Pelona schists, which cover a triangular area of about 3½ square miles in the southeast corner of the quadrangle. This series is composed principally of rather coarse, granular mica-schist, in some places slaty and in others almost impure quartzite, and associated with coarsely foliated grayish gneiss. The series has been assigned tentatively to the Proterozoic.

Two bodies of gneiss occur in addition to that mapped with the schists, one lying east and the other west of the Ridge Route. The gneiss is dark gray rock, composed mainly of quartz, feldspar, and mica; the eastern body is closely intermingled with marble and quartzite; and both have been intruded by Jurassic granitic rocks. The age assigned is Paleozoic.

Granitic intrusive rocks cover an area of approximately 30 square miles; those in the northeastern part belong to the Liebre-Sawmill Mountain mass, whereas those in the western part presumably extend west to connect with similar rocks in the Mount Pinos Quadrangle.

The rocks are predominantly granodiorite in composition, although gradations are found into quartz diorite on the one hand and true granite on the other. Anorthosite is abundant as float in the vicinity of the western exposure. Both bodies are intrusive into the older metamorphic rocks. The age is considered to be Jurassic.

SEDIMENTARY ROCKS

Martinez formation (*Lower Eocene or Paleocene*).—The oldest unmetamorphosed sedimentary rocks known in the southern part of the Tejon Quadrangle are lowermost Eocene. Apparently either no Cretaceous seas extended over this area, or Cretaceous rocks that may have been deposited were eroded away prior to the deposition of the Martinez. Where the base of the Martinez is exposed, the underlying rocks are found to be crystalline, with no intervening sedimentary beds.

Two unconnected bodies of rocks in the area have been mapped by the writer as Martinez. One is a thick series of sediments east of the Ridge Route and containing definite Martinez fossils. The other lies west of the Ridge Route and has been assigned to the Martinez on the bases of lithologic character and stratigraphic position. A third body, lying immediately west of and paralleling the Ridge Route, has been mapped tentatively as Modelo (Upper Miocene), but may well be Martinez also.

The formation is marine in origin and is composed of conglomerate, sandstone, and shale. The conglomerate is the outstanding characteristic of the exposures, being extremely thick, and consisting of well rounded phenoclasts, as large as 2 feet in diameter, of granodiorite, gneiss, quartzite, and rhyolite porphyry. The third body, previously mentioned, is composed almost entirely of very coarse breccia.

Domengine formation (*upper Middle Eocene*).—Rocks of Domengine age occur in the Piru Creek district where they overlie supposed Martinez beds farther north. Farther south, as a result of overturning, they overlie younger Sespe and Vaqueros beds. The rocks, which probably mark the eastern margin of transgression of the Middle Eocene sea, are marine in origin and contain rather abundant fossils. Conglomerate, sandstone, and shale comprise the formation, the shale predominating.

Sespe formation (*Oligocene*).—Three isolated outcrops of rocks have been assigned to the Sespe formation. All are continental in origin and because of certain common characteristics logically should be considered as correlatives, although being unfossiliferous, it is possible that none of them belongs to the Sespe, or that they differ in

age. The strata as a whole are rather poorly sorted conglomerates, sandstones, and mudstones of varied composition and in most places somewhat highly colored. The outcrops occur in the eastern part of the area between San Francisquito and Elizabeth Lake canyons, in the northern part along Castaic Creek,[2a] and in the western part in the vicinity of Canton Canyon.

Vaqueros formation (*Lower Miocene*).—Vaqueros beds are found only in the western part of the area extending in a narrow belt, in few places as wide as a mile, from a short distance east of Canton Canyon beyond the margin of the territory mapped. The formation is composed of marine sandstones and shales with a basal section of very coarse conglomerate. These beds, which are the most fossiliferous of all those in the area, probably mark the easternmost edge of the Vaqueros sea.

Temblor formation (*Middle Miocene*).—Lying above the Vaqueros with a marked angular unconformity are strata of Middle Miocene age. These consist of coarse, poorly sorted, basal conglomerate of little lateral constancy, followed by a series of hard cherty shales interbedded with a few thin sandstone layers. The upper limit of the beds is indefinite, since the overlying Modelo beds are also shale and both formations are unfossiliferous along the contact. Fossils are scarce and have been found only in float, the lithologic character and position of which indicated its derivation from these beds.

Mint Canyon formation (*Upper Miocene*).—Land-laid beds corresponding in many ways with the Sespe formation are found in the southeastern part of the area. These are a northern extension of the type Mint Canyon beds in the quadrangle immediately south, and they extend in a rapidly narrowing band across San Francisquito Canyon to a point a short distance west of Elizabeth Lake Canyon. Here they apparently grade laterally into basal Modelo marine beds and they also show evidence of grading upward into marine Modelo.

The formation comprises a series of heavy-bedded, poorly sorted conglomerates and sandstones, generally rather highly colored, and in many places cross bedded. The character of the beds indicates that they were deposited as alluvial fan material and valley fill. A few scattered vertebrate fossils occur in the lower beds.

Modelo formation (*Upper Miocene*).—The term "Modelo" is used in this paper to designate marine beds of Upper Miocene age. Such beds occupy approximately one-fifth of the area mapped. One exposure occurs in the Piru Creek district as the northern extension of the

[2a] "Castaic" is now the preferred spelling for a locality name sometimes spelled "Castac."

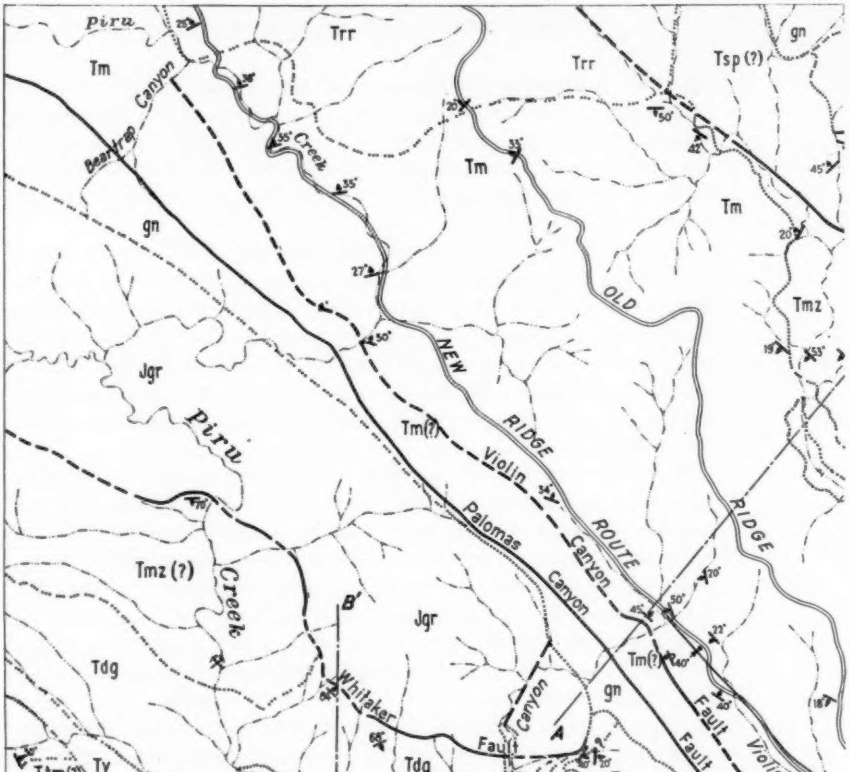
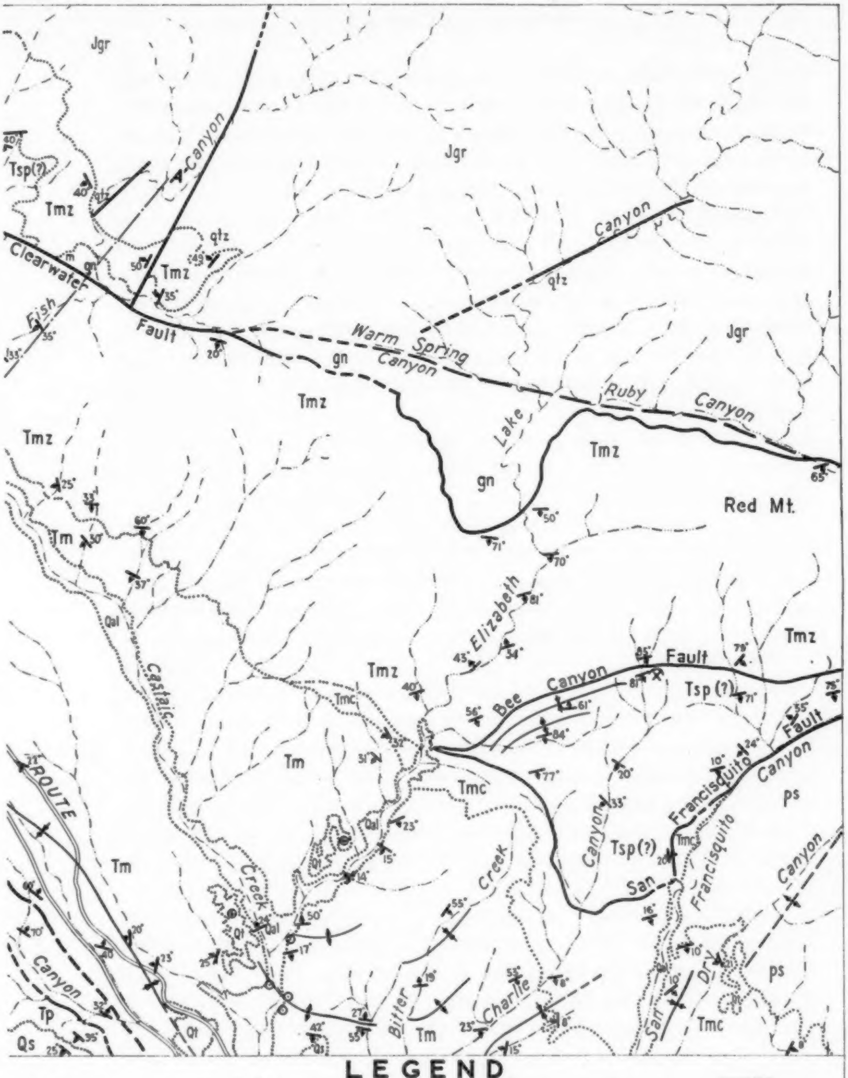


Fig. 1.—Geologic map of part



of Tejon Quadrangle, California.

type Modelo beds, and another in the middle part of the area, along the Ridge Route. The former consists principally of shales though it includes some very thick strata of interbedded sandstone which are more prominent farther west. As previously mentioned, these beds are conformable with the underlying Temblor.

The main body of Modelo rocks is in the central part of the area. These rocks are chiefly alternating sandstones and shales with well developed conglomerate at the base. They have been folded into a long asymmetric syncline, resulting in a repetition of beds on the two sides of the axis. The conglomerate on the northeastern side is of the normal basal type, whereas that on the opposite limb of the syncline is very thick, coarse breccia, apparently formed at the foot of an actively rising fault scarp, since it is bounded on the southwest by the Palomas Canyon fault. It is separated from the upper beds of the Modelo by another fault and it is entirely possible that this breccia is not Modelo at all.

The formation as a whole is marine in origin, although some of the uppermost beds of the central exposure show certain characteristics that suggest their being lacustrine. Fossils occur in the western body and in the lower beds of the other exposure, although those found in the breccia were too fragmentary to permit identification.

Pico formation (*Pliocene*).—Marine beds of Pliocene age occur in the southern part of the Tejon Quadrangle between Palomas Canyon and Devil Canyon, and extend northward almost to Canton Canyon. The formation consists principally of light-colored, rather loosely consolidated sandstone and conglomerate with a heavy conglomerate member at the base and a considerable thickness of overlying shale. Parts of the formation are very fossiliferous. This occurrence marks the most northerly advance of the Pliocene sea that occupied the eastern part of the Ventura basin.

Ridge Route formation (*Pliocene?*).—Continental beds occur in the northern part of the area, overlying with a slight angular discordance the upper sandstones and shales of the Modelo. The strata consist of rather well bedded sandstones and shales with many beds of conglomerate, and appear to be lacustrine in origin, the only megafossils found thus far being fresh-water mollusks and a horse tooth, which came from north of the area mapped. The formation has been tentatively assigned to the Pliocene on the basis of stratigraphic position; it may be the equivalent of the Saugus formation.

Saugus formation (*Lower Pleistocene*).—"Saugus" is used by the writer to specify certain continental deposits unconformably overlying marine Pliocene beds, and cropping out in the extreme southern

part of the quadrangle. The formation varies in lithologic character with the nature of the underlying beds, but consists in general of rather loosely consolidated sandstone and conglomerate, characterized by poor sorting and poorly defined bedding. The rocks are unfossiliferous, their age having been assigned by the writer on the basis of the unconformity separating them from the underlying Pliocene strata.

Terraces (*Upper Pleistocene*).—Terrace deposits are well developed in some of the larger canyons, and terrace material is found capping many of the ridges in the southeastern part of the area. At least three stages of stillstand in the downward cutting of the streams are represented. The material is unconsolidated and poorly bedded, and varies in composition from place to place. The attitude of the beds in general is horizontal, but one exposure close to the Palomas Canyon fault shows decided tilting.

Alluvium (*Recent*).—Alluvium covers the floors of all the larger valleys in the area and extends far up many of the canyons. Its depth apparently is not great, since a well drilled in the bed of Castaic Creek, approximately one mile north of the south boundary of the quadrangle, logged 80 feet of alluvial fill. The alluvium is nowhere within the area known to have been disturbed by recent faulting.

STRUCTURE

GENERAL

The southeastern part of the Tejon Quadrangle offers some rather complex structural problems. One of the difficulties in solving them arises from the impossibility of determining definitely the ages of many of the members involved. The problems in themselves, however, are stimulating and are presented with such conclusions as it has been possible for the writer to draw.

The area is divided into three major structural units, all of which trend northwest and southeast, roughly parallel with the general trend of the great San Andreas fault, which lies only a few miles northeast of the region mapped. The first is the Red Rock Mountain unit which occupies the northeastern part of the area and is so named for its most prominent topographic feature. It is composed principally of crystalline rocks, although it has a covering of sediments in the northwestern part; and it is separated from the adjacent unit farther southwest by the Clearwater fault.

The second is designated the Castaic unit. It consists chiefly of sedimentary rocks and possibly should be considered to terminate against the Pelona schists farther southeast. However, in view of the

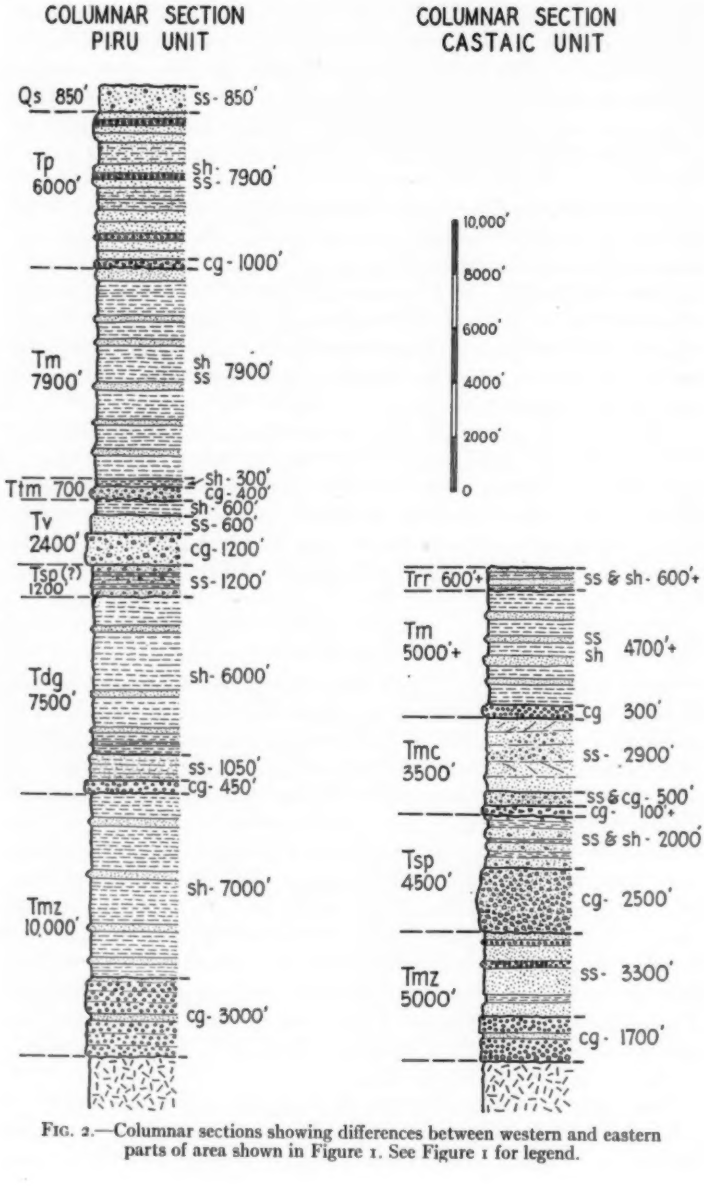


FIG. 2.—Columnar sections showing differences between western and eastern parts of area shown in Figure 1. See Figure 1 for legend.

fact that the sediments in part rest on the schists with a depositional contact, it seems more logical to consider the latter as part of the crystalline basement of the unit. It is possible that this part of the area existed as a graben during much of Tertiary time, as evidenced by the thick covering of sediments and the fact that it is bounded on the northeast and the southwest by faults, along which it has been depressed relative to the adjacent units.

The remaining part of the area is included in the Piru unit, the rocks of which are partly crystalline and partly sedimentary. How far west this unit may extend can be determined only by further field work in that part of the quadrangle between Piru and Sespe creeks, a project to be undertaken by the writer in the near future. The Piru unit is complicated by differential movement within itself, especially along the Agua Blanca overturn.

FAULTS

Clearwater fault.—The Clearwater fault is named for its evident connection with the origin of a canyon of that name in the Elizabeth Lake Quadrangle. It is a continuation of what Simpson has called the Bouquet Canyon fault,[3] but since the name Clearwater was used at an earlier date by R. T. Hill and F. A. Nickell in unpublished papers, and by the writer in a brief paper given before the Geological Society of America,[4] it is deemed to have priority.

The fault is well exposed in many places, the most accessible of which is in Elizabeth Lake Canyon, where cuts made in road-building afford excellent opportunities for study. Other good exposures are in Fish Canyon and along Castaic Creek. A rather wide crushed zone exists along the fault, particularly in the crystalline rocks. This is as wide as a quarter of a mile in some places, with granite and gneiss shattered and slickensided throughout. Springs of warm water occur in this zone.

The topography shows very clearly the control exercised by the crushed zone, in the series of canyons all in line and in the notched divides between their heads. Ruby and Warm Spring canyons and the east fork of Fish Canyon owe their general alignment to the presence of the Clearwater fault, as does also the western fork of Salt Creek. The peculiar southward swing made by the main fault trace in Elizabeth Lake Canyon is attributed to warping of the area in a direction

[3] E. C. Simpson, "Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California," *California Jour. Mines Geol.*, Vol. 30, No. 4 (October, 1934), p. 405.

[4] T. Clements, "Structure of a Portion of the Tejon Quadrangle, California." Abstract, *Pan-Amer. Geol.*, Vol. 54, No. 2 (1930), p. 159.

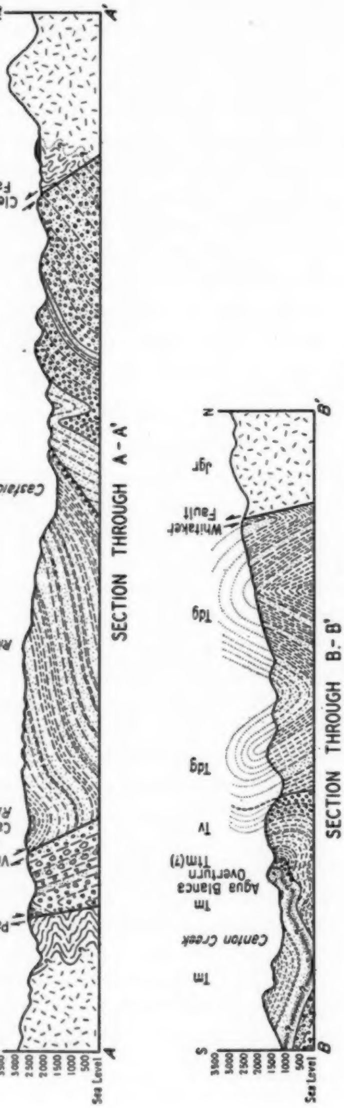


FIG. 3.—Structure sections. See Figure 1 for legend.

almost at right angles to the trend of the principal structures after the major part of the faulting had taken place. The lobe of crystalline rocks thus formed has been cut off by a more recent break. Present stream channels have been determined largely by this later faulting, although it is not clearly marked in the field where it does not follow the line of earlier movements.

A study of the fault surface as exposed in various localities shows it to have a general strike that ranges from N. 60° to 75° W. The former is the prevailing figure west of Castaic Creek, the latter east. The dip varies from 60° SW. to vertical, and even northeast, as shown in section *AA'* (Fig. 3). Since the northeastern side has been uplifted relative to the other, the fault may be classed as either normal or reverse, depending on the point of observation.

Displacement along the fault appears to have been of two very different natures. Vertical movement, with the Red Rock Mountain unit relatively uplifted, is indicated by the presence in the vicinity of Fish Canyon of Martinez basal beds and underlying crystalline rocks faulted up against beds much higher in the Martinez section. The minimum vertical displacement at this particular point is estimated to be nearly 4,000 feet. That this faulting was of a hinge type, with greatest throw along the southeastern part, is suggested by the fact that east of Elizabeth Lake Canyon no sediments are found on the upthrown side, though from Fish Canyon west progressively higher beds of the Martinez are exposed at the surface.

Horizontal displacement is shown by the presence of the supposed Sespe rocks lapping up on the Martinez on the northeastern side of the fault, whereas they are absent on the southwestern side. At first glance this might seem to be simply the result of the vertical faulting; however, these rocks have been preserved on the upthrown side and are missing from the other, quite the reverse of what would be expected as the result of vertical faulting. As younger overlying beds have hidden any trace of the offset Sespe (?) on the northwest, it is impossible to determine the maximum amount of movement. The minimum is slightly more than 2 miles. The Red Rock Mountain unit has been displaced toward the southeast relative to the Castaic unit, the direction of movement being similar to that along the San Andreas fault. Well preserved horizontal grooves and striae indicate that the horizontal movement took place after the major part of the vertical displacement.

Because of the impossibility of accurately dating the supposed Sespe, it is difficult to determine definitely the times of activity of the Clearwater fault. The first recorded movement, the major vertical

displacement, occurred after Martinez time (early Eocene or Paleocene) and prior to the deposition of the Sespe (Oligocene?). The horizontal slipping took place following the latter event, but before the Modelo (Upper Miocene) had been deposited, since a small tongue of Modelo rocks projecting across the fault and resting on the Sespe (?) has been broken but not offset horizontally. It is quite possible that this was concurrent with the first movement on the San Andreas, often considered to have taken place during the Miocene.

Further vertical displacement occurred following deposition of the Ridge Route formation (Pliocene?), since these rocks have been disturbed along the fault. Again inability definitely to date this formation clouds the exact time determination. The previously mentioned warping took place between the time of horizontal movement and that of the last vertical displacement, since Miocene deposits are affected by the warping and the Warm Spring Canyon extension of the Clearwater fault is not. It seems likely that this last disturbance came at the beginning of, or in, the Pleistocene, possibly at the break between the Saugus and the terraces.

Palomas Canyon fault.—The Palomas Canyon fault is named for its excellent exposure in the canyon of the same name. A study of the topography suggests that the fault continues northwest beyond the area herein considered, and it has been mapped by Kew[5] as extending southeast to connect with the San Gabriel fault zone near Saugus.

In addition to the exposures in Palomas Canyon, the fault is visible in upper Canton Canyon just below Oak Flat, in Piru Canyon a short distance downstream from the point where the new Ridge Route first enters the canyon, and on various ridges on both sides of the canyons named. It is very prominent where crossed, showing a crushed zone that varies from a few feet to several hundred yards in width, with considerable gouge and slickenside. It is only where it passes altogether into sedimentary rocks, as it does in the southern part of the quadrangle, that it becomes difficult to locate accurately.

The straight trace of the fault across the map is indicative of its high angle. Where exposed in upper Canton Canyon the strike is N. 40° W. and the dip is 80° NE. The surface flattens somewhat in Piru Canyon, where the dip is approximately 60° NE.; at no place does it appear less than this.

Movement along this fault has been much more simple in its nature than that along the Clearwater fault. There is evidence of vertical displacement only, with the Piru unit relatively upthrown,

[5] Personal communication.

although the sharp fold in the breccia adjacent to the fault suggests a reversal in the direction of movement (Fig. 3). The coarseness and angularity of the material comprising this breccia indicate its formation at the foot of the scarp of the Palomas Canyon fault, the blocks all having been derived from the crystalline rocks of the Piru unit. The latter apparently was actively rising during the formation of the breccia, whose very considerable thickness implies a throw of many hundreds and perhaps thousands of feet. The fault shows the characteristics of a normal fault throughout its course.

The earliest movement, of which there is a record, is that correlated with the formation of the breccia, but whether the latter is Modelo, Martinez, or even Sespe, is purely a matter of conjecture. If the area between the Clearwater and the Palomas Canyon faults was a graben, then movements along the two must have been related in time. This, however, would fit none of the foregoing assumptions as to the age of the breccia, since the principal vertical displacement along the Clearwater fault seems most likely to have been post-Martinez and pre-Sespe. It is quite possible that this early movement along the Palomas Canyon fault occurred during the profound break indicated by the unconformity between the Lower and Middle Miocene beds, the fault continuing to be active during the early part of late Miocene time. This is another of the problems that must look to the future for final solution.

Later movement is shown by the disturbance of Pico (Pliocene) beds and also of the Saugus (early Pleistocene). The higher dips in the former as compared with the latter may be the result of activity along the fault both before and after deposition of the Saugus, but may likewise have been brought about by regional tilting at the end of the Pliocene with disturbance of both sets of beds by faulting in post-Saugus time (probably Middle Pleistocene). Late Pleistocene adjustment along the Palomas Canyon fault is indicated by the disturbance of young terrace material just east of the fault. No break in the alluvium has been observed.

San Francisquito fault.—The most interesting of all the minor faults is that which has been named the San Francisquito fault. Passing as it did under the St. Francis dam, it was indirectly responsible for the failure of the dam in 1928, and received considerable attention at that time. It forms the boundary between a patch of the supposed Sespe and the Pelona schists from the east margin of the quadrangle to about a half mile below the former dam site, where Mint Canyon beds are interposed above the schists and become the footwall rocks. Continuing down the canyon to a short distance below Power House

No. 2, the fault swings west across the ridge into Charlie Canyon. Thence it is traceable northwest to a point just east of Elizabeth Lake Canyon, where at its intersection with the Bee Canyon fault it apparently ends.

The fault can be seen to excellent advantage almost continuously from the former site of the dam to where it crosses the ridge into Charlie Canyon. Above the dam site it is obscured by alluvium, and below, on the ridge where it leaves the canyon, thick brush makes observations impossible. It is very well exposed in the west fork of Charlie Canyon.

Where exposed at the dam site, the fault strikes N. 55° E. and dips at an angle of 44° NW. This is a comparatively low angle and suggests a thrust, although the fact that older rocks comprise the footwall favors its being of the type usually designated as normal. At the locality below the dam where Mint Canyon beds first appear, the latter rest on the schists with a depositional contact, and the fault here is between the Mint Canyon formation and the overlying older red beds of the supposed Sespe. The latter are highly fractured, and stained a deep maroon by hematite deposited by water moving along the fractured zone. At the contact there is at least a foot of unmistakable gouge. This is composed largely of crushed schist from the boulders in the underlying basal conglomerate of the Mint Canyon formation, and is leached to light gray. The superposition of Sespe (?) on the younger beds is rather conclusive evidence of overthrusting.

The overthrust nature of the fault is maintained down the canyon, but where exposed in Charlie Canyon it has assumed the character of a normal fault, the plane dipping approximately 65° SW., or under the Miocene sediments. It continues as such to its intersection with the Bee Canyon fault. Since it is so closely related to the latter, its time of movement and causative forces will be discussed following a general discussion of that fault.

Bee Canyon fault.—The Bee Canyon fault forms the Martinez-Sespe (?) contact between San Francisquito and Elizabeth Lake canyons, its name coming from its probable influence in the formation of Bee Canyon, which is a short distance east of the Tejon Quadrangle. The break is visible at the base of the Martinez hills forming the northern rim of the basin of Sespe (?), and is marked by a crushed zone that in places is 200–300 feet wide, although generally narrower. This is easily followed because of the absence of all vegetation excepting sage, whereas the unbroken rocks on either side support a heavy chaparral cover. The ridges show decided notches where crossed by the fault, and both breccia and slickensided surfaces are found.

The general strike of the fault is northeast, in many places N. 75° E. For a short distance it changes to southeast. The attitude of the fault surface approaches the vertical, although because of slumping of the crushed material in the transverse canyons, no good section was found and no satisfactory dip observations could be made. Direction of movement along the fault appears to have been relatively upward on the north side and downward on the south side, the fault being classed as normal.

It is the belief of the writer that neither the Bee Canyon fault nor the San Francisquito fault penetrates to great depths, the probability being that they meet beneath the Sespe (?). The Sespe, deposited as a comparatively thin film in the basin between the Martinez on one side and the schists on the other, has been folded and compressed, but has acted as a unit. Thus the forces that brought about the folding of the Martinez and Mint Canyon beds appear to have folded the Sespe (?) also, but rather than folding into and with the other formations, the Sespe has been squeezed between the much more competent Martinez and schist, and forced to ride up on the latter and its overlying Mint Canyon beds, at the same time being forced down along the northern margin. It is difficult to explain otherwise the change in the San Francisquito fault from overthrust to normal along its strike, and particularly the abrupt ending of both faults where they come together east of Elizabeth Lake Canyon.

The exact time of activity of the Bee Canyon and San Francisquito faults is difficult to fix. Since Mint Canyon beds are affected, the movement must have been no earlier than late Miocene. Terrace material capping the ridge between the San Francisquito and Charlie canyons has not been disturbed by the faulting; consequently an upper time limit of late Pleistocene is established. If the folding and thrusting of the Sespe (?) occurred at the same time as the already-mentioned upwarp athwart the general structural lines, then the time of movement along the two faults may be dated as probably post-Pliocene and pre-Pleistocene.

Violin Canyon fault.—The Violin Canyon fault has been traced northwest from the south boundary of the quadrangle to the northwest corner of the area mapped, parallel with, and a short distance east of, the Palomas Canyon fault. It is clearly exposed in only a few places, the best localities for observation being where it crosses the lower end of Violin Canyon and in the vicinity of Oak Flat. In other places its location has been based largely on topographic evidence. The fault separates the coarse breccia that has been taken as the basal part of the Modelo on the western side of the Castaic basin

from the incompetent shales and sandstones that compose the upper part of the same formation. As pointed out before, this breccia may or may not be Modelo. The fault has been named from its obvious connection with the origin of Violin Canyon.

The attitude of the fault surface is not greatly different from that of the beds on both sides, observations giving dips of 50°–60° NE. and a strike approximately northwest. The breccia shows little effect of the movement, but the weak shales have been dragged to verticality and even overturned along the fault. These beds apparently have taken up some of the movement by slippage along their bedding planes.

The fault is of the normal type with the older breccia on the upthrown side. However, it appears that this fault, in spite of its normal character, was formed by compression, since it probably occurred contemporaneously with the Castaic syncline discussed later. The amount of throw as estimated from the thickness of beds missing on the west limb of the syncline is about 3,500 feet.

Whitaker fault.—The Whitaker fault occurs in the Piru unit, separating the granitic mass of which Whitaker Peak is the most prominent point from Tertiary sediments farther south and west. The fault surface is well exposed in Piru Canyon and in Canton Canyon, as well as in many of the smaller channels crossed. It dips steeply, varying from 60° to 80° generally northeast, although a reversal of direction was noted in one locality.

Movement apparently has been relatively upward on the northern side, since all sediments have been stripped from the crystalline mass. This makes the fault of the high-angle reverse type with the granitic rocks riding up on the sediments. The resistant Martinez conglomerate is highly fractured adjacent to the fault; it has many slickensided surfaces, although only a very thin seam of gouge is present. The soft Domengine shales show great contortion, with some overturning of beds in the vicinity of Canton Canyon.

The disturbance was later than Middle Eocene in time, since Domengine beds are affected. As Modelo and probably Temblor beds rest on the granite with a depositional contact, the movement must have been pre-Upper and possibly pre-Middle Miocene. At present it is impossible to date it closer.

Other faults.—Several smaller faults have been recorded, of which one in Fish Canyon is particularly interesting. This strikes N. 30° E. with a slight change in direction along its northern extent. The fault surface is practically vertical. Its trace is well marked by an alignment of topographic features, part of the north fork of Fish Canyon having

been determined by its presence. Some horizontal movement is indicated by the offsetting of basal beds of the Martinez along its strike, although the amount of offset is not more than 200–300 yards. The fault is obviously post-Martinez and is also pre-Clearwater, since it is not traceable across the Clearwater fault. Its offset southern extension has not been found.

Other faults of minor importance exist in Fish Canyon west of the one described, in upper Castaic Canyon, and also in the crystalline rocks of Elizabeth Lake and Canton canyons. Many of the massive beds of sedimentary rocks are crossed by numerous insignificant faults of slight displacement.

FOLDS

The major fold in the area is the Castaic syncline, the axis of which roughly parallels the southwestern margin of the Castaic unit. Martinez and Modelo rocks dipping west form the long gently sloping eastern limb of the asymmetric fold, the western limb turning up abruptly against the Palomas Canyon fault. The Modelo shales show an extreme degree of contortion, readily visible in cuts along both the old and new Ridge Route. Where squeezed against the hard breccia along the western side, the shales and thin sandstone beds have been completely overturned and faulted.

Kew, in his mapping farther south,[6] does not show a continuation of this syncline, and it seems probable that it swings around toward the northeast, its continuation being manifested in a smaller syncline between San Francisquito and Charlie canyons. This is suggested by the sinuous character of the small anticline that crosses Castaic Creek a mile north of the quadrangle boundary, and from an original parallelism with the Castaic syncline, swings toward the east and apparently is continued northeast by the anticline between Bitter Creek and Charlie Canyon.

It will be noted from an inspection of the map (Fig. 1) that the deflection of the Castaic syncline as well as of the minor anticline is in line with the great southward swing of the Clearwater fault and with the less well marked but still distinct curvature of the two sedimentary contacts crossing Elizabeth Lake Canyon between. The only conclusion possible to reach from these observed facts is that a rather large transverse upwarp has developed athwart the general structural lines, affecting not only the Castaic unit but likewise a part of the Red Rock Mountain unit. This feature is of such magnitude that at no time has it been possible to see more than a hint of it in the field, but there

[6] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull.* 753 (1924).

can be no question as to its existence. The writer has named this the Elizabeth Lake Canyon upwarp.

The most prominent fold in the Piru Creek region is the Agua Blanca overturn, the axis of which has not been indicated on the map. This first becomes visible just east of Canton Canyon and extends west for an unknown distance. Complete overturning of the beds involved is not found all along the structure, but where well exposed in Piru Canyon the beds very distinctly are overturned toward the south, and this seems to be the rule as far west as observation has been carried by the writer. Domengine, Sespe(?), Vaqueros, Temblor, and Modelo beds are affected by the overturn. In addition to the overturning, there has been a certain amount of overthrust faulting, with Domengine and Sespe(?) beds pushed over Vaqueros, and the latter in turn perhaps thrust over Temblor. The overturn has been rendered somewhat more complex east of Piru Creek by smaller folds whose axial planes trend at oblique angles to that of the Agua Blanca fold.

There are many minor folds in the southern part of the area. These are particularly prominent in the Modelo and Pico strata between Piru Creek and Palomas Canyon, and also west of the former. An attempt was made to map some of these, although they are considered to be of minor importance in the interpretation of structural history since they are closely related to the larger structures. Small, tightly appressed folds in the Sespe(?) of the San Francisquito Creek region give some clue to the deformation to which the formation as a whole has been subjected.

Dips and strikes of the still visible bedding planes of the Pelona schists give evidence of a general anticlinal structure, complicated by minor folding. That flow cleavage had developed prior to the folding and not as a consequence of the forces causing the folding is indicated by the parallelism between flow cleavage and bedding planes, rather than between the cleavage and the axial plane of the fold. Jointing is well developed in the schists.

STRUCTURAL HISTORY

Broadly interpreted, the structural details just described tend to show that compressive forces have been active in this region for a vast period of time. Some of these forces have been static, as in the case of the development of flow cleavage in the schists parallel with the bedding. Largely, however, the forces have been dynamic, and partly, rotational in their application. This is indicated by the thrust faults and folds, and particularly by the horizontal movement along some of the faults as the result of shearing stresses. Though it is true that

tension causes normal faults, it is not necessarily true that all normal faults are caused by tension; therefore, some of the normal faults of the region are likewise the result of compression.

It is difficult to say at what time the forces first became active. Doubtless there was uplift at the time of the intrusion of the Jurassic batholith, and it is possible that the anticline developed in the schists dates from this time. That there also must have been uplift at the end of the Mesozoic era is indicated by the great thickness of the Martinez conglomerate.

The first activity of the forces that can be dated more closely than those previously mentioned came after the deposition of the Martinez and prior to Sespe(?) deposition, when the Red Rock Mountain unit was uplifted and partly denuded of Martinez sediments. The rather considerable remaining thickness of basal Martinez lying beneath the Sespe(?) suggests that the uplift was not great and was probably of the hinge type with decreasing displacement toward the northwest.

Horizontal movement along the Clearwater fault took place after Sespe(?) time, but apparently before Modelo, since deposits of the latter age have not been displaced laterally. It is possible that uplift of the Piru unit was contemporaneous with this, judged from the postulated conditions of deposition of the breccia of supposed Modelo age adjacent to the Palomas Canyon fault. Probably movement along the Whitaker fault also occurred at this time. The marked unconformity at the base of the Temblor suggests that this period of diastrophism came between the Vaqueros and Temblor ages.

Further compression resulted in the folding of the Modelo beds into the Castaic syncline and also resulted in the Agua Blanca overturn, in which Modelo strata are considerably involved. The Violin Canyon fault was formed at this time. It can not be stated definitely whether this came before or after Pico deposition, since the overturn dies out farther east, but the Pico beds do not appear to have been affected.

The last great period of compression also was marked by shearing stresses. It is apparent that the Castaic unit was unable to yield at this time by slipping along the bounding faults either horizontally or vertically, as it had hitherto done, and the rocks were folded into the Elizabeth Lake Canyon upwarp. The weak Sespe(?) strata in the shallow basin between the relatively strong Martinez and the unyielding crystalline rocks were forced into tight folds and thrust over the Mint Canyon beds and the Pelona schists, dropping relative to the Martinez along the Bee Canyon fault. This period may have come

at the end of Pliocene time or during the Pleistocene. Since it is evident that the Warm Spring branch of the Clearwater fault formed after the upwarp, and a very considerable amount of erosion has taken place along this fault since its formation, the earlier date for the upwarp seems more logical. This would date the last recorded movement along the Clearwater fault and its branch as either immediately following the upwarp—that is, post-Pliocene and pre-Pleistocene—or as Middle Pleistocene, resulting perhaps from relaxation following the compression.

General uplift of the region as a whole in late Pleistocene time is indicated by the terraces along the principal stream courses; at least three stages are evidenced by the three terrace levels. The tilting of the older gravels in the vicinity of the Palomas Canyon fault suggests some differential movement along this fault during one of the later stages of uplift. No disturbance of alluvium has been noted by the writer.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 233-245, 3 FIGS.

RECONNAISSANCE GEOLOGY IN STATE OF ANZOATEGUI, VENEZUELA, SOUTH AMERICA[1]

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ABSTRACT

After a brief discussion on the general stratigraphy of the state of Anzoategui, a reconstruction of geological events in the Anzoategui geosynclinal basin is attempted. Tentative conclusions are drawn from heavy-mineral work and are incorporated in the argument of geological history. Suppositions as to the present shape and present sedimentation of the geosyncline are then drawn from the results and interpretations of seismic work with which the writer was associated. Finally, field practice in seismometry is briefly discussed.

INTRODUCTION

Except for such data as fall naturally within R. A. Liddle's comprehensive work on Venezuela, little or nothing has been published on the geology of Anzoategui. This paucity of data is not due to lack of exploration, since more than one generation of geologists has made field studies of selected areas in the state. These studies have been undertaken with a view to evaluating concessions already held by companies, or with a view to the acquiring of other concessions with reasonable petroleum prospects. The nature of such work has invariably made the results confidential, especially because there still remained considerable acreage for purchase. This condition no longer exists, for the major part of the state is already leased. It is therefore to be hoped that this paper will not only induce discussion, but that it will bring further and fuller contributions from those best qualified to write on the subject.

The paper deals in restricted fashion with the stratigraphy and geology of Anzoategui. The role of heavy minerals in reconstructing the Anzoategui geosyncline is indicated, and geophysical studies in this connection are also discussed.

ACKNOWLEDGMENTS

The writer wishes to thank Alfred Meyer and his codirectors for their kindness in permitting publication, and E. E. Boyland for his encouragement and advice. The writer has had the privilege of being in

[1] Manuscript received, November 4, 1936.

[2] Caracas Petroleum Corporation, Apartado 89.

the field with V. C. Illing, not only in various districts of Venezuela but also in the Antilles.

EXTENT OF ANZOATEGUI

Anzoategui has an area of approximately 44,000 square kilometers. It is bounded on the north by the Caribbean Sea and on the south by the Orinoco River. Within this area, such geological phenomena as mountain-building, thrusting, release-faulting, folding, overlap, and buttress may be seen.

FIG. 1.—Outline map of states of Venezuela.

STRATIGRAPHY

Archean.—The Orinoco River in Anzoategui practically marks the north line of exposed granitic and gneissic material. It is generally accepted that this exposed mass is part of the great Brazilian shield of presumably Archean age, and that it has formed shore lines for successive series of sediments in the state of Anzoategui proper.

Paleozoic.—A series of quartzites and semi-schistose material is sporadically exposed on the north bank of the Orinoco River. Because of their lithologic character, they have been correlated by geologists with somewhat better examined Paleozoic material in the Guayana highlands south of the Orinoco River. It may be assumed that this series was deposited in basins formed within the Archean material

previously mentioned. Further, it is assumed that within the state of Anzoategui, all but a few remnants were removed in the southern area during an erosion period which lasted throughout parts of the Paleozoic and Mesozoic eras.

Lower Cretaceous.—In the northeastern corner of the state, saccharoidal quartz sandstones appear in the coastal region. These are comparable with the Barranquin sandstones which Liddle has described as occurring in broad areas in the adjacent state of Monagas. The writer has seen few fossils within this lithological unit, but its field relations with other sediments render it probable that its age is Lower Cretaceous.

Middle Cretaceous.—Near Bergantin, the writer has noticed fossiliferous cherty limestones. These are entirely comparable, both in lithologic character and apparent fossil content, with the limestone seen at El Cantil, Liddle's type locality for the El Cantil limestone in the abjacent state of Monagas. Determinations of El Cantil fossils indicate Middle Cretaceous age, an identification which has been confirmed by others.

Upper Cretaceous.—Various localities in the foothills of northeastern Anzoategui show disturbed black shales with a few thin sandstones lying above fossiliferous Middle Cretaceous limestones. Although the writer has made no fossil collections from these shales, their position in the main succession and their similarity to those he has seen at the Guayuta type locality farther east, render it probable that they are Upper Cretaceous in age.

Cretaceous-Eocene transition.—Following detailed studies of Monagas type localities, Liddle advances the theory that an important unconformity separates the Cretaceous and Eocene. The writer's own studies have not been detailed, but they do not point to any obvious unconformity between the two periods. At many places in the foothills, there are apparent great thicknesses of shales that suggest an unchanged facies crossing the Cretaceous-Eocene time-line. A detailed attack on the problem might reveal the presence of organic remains in part of the shales comparable with those referred to the Paleocene period in Europe. From a structural point of view, the problem is rendered difficult and perhaps incapable of solution by minor faulting and crumpling of the shales themselves.

Eocene.—The typical Eocene deposits both of this state and of others are massive ripple-marked sandstones of the quartzitic type together with interbedded shales or clays. Plant remains are numerous within the series but do not fix the age of the sandstones. Only where the facies is intermittently marine, or where a later stage is preserved,

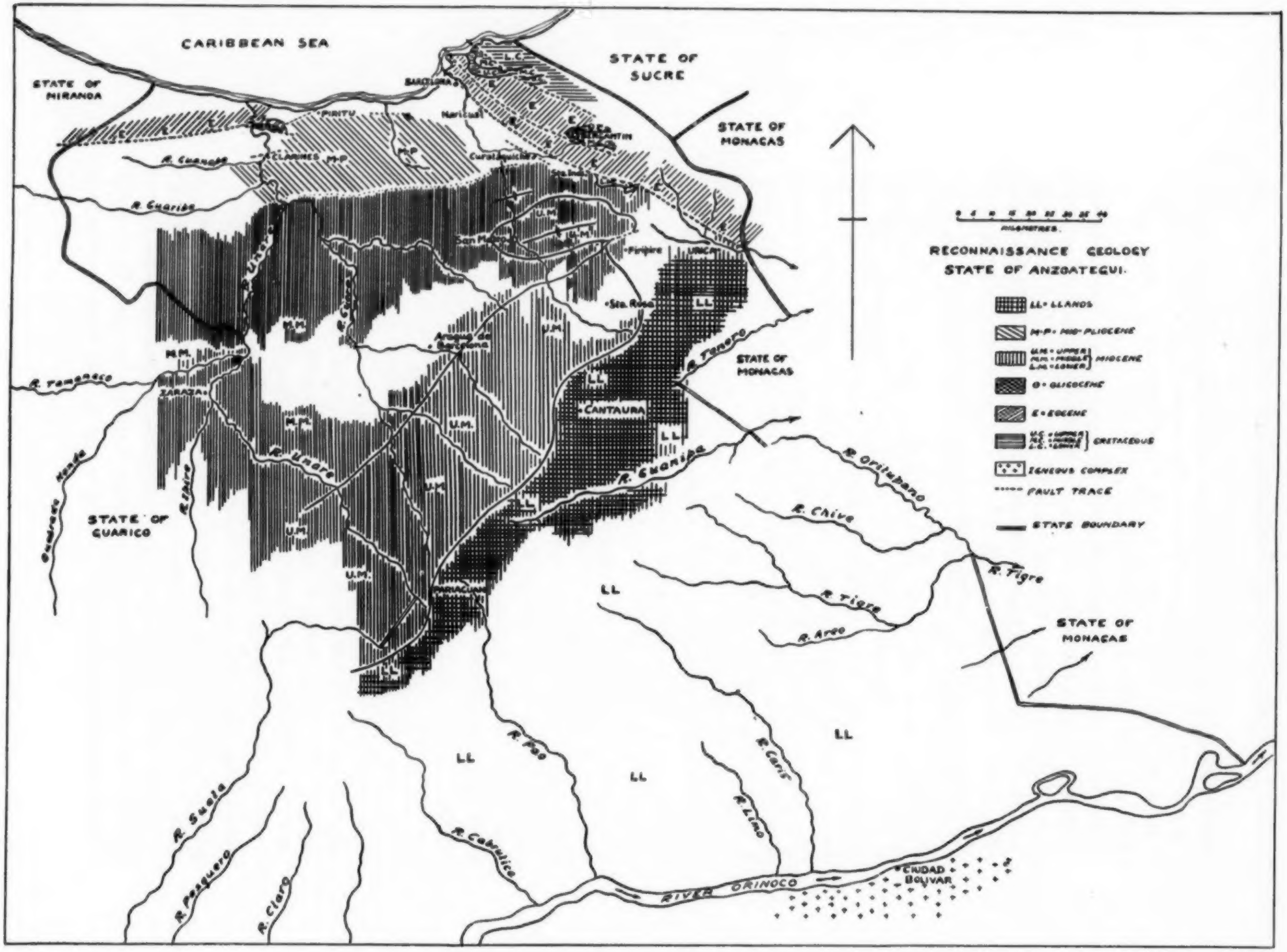

FIG. 2.—Reconnaissance geological map of state of Anzoategui, Venezuela.

are marine fossils found here and there. Thus Liddle records the typical *Venericor* (*Venericardia*) *planicosta* from a locality near Urica in Anzoategui. The writer has also found in this general vicinity, material with shell fragments and a few casts that suggest members of the *Carditidae*.

Upper Eocene-Oligocene.—North of Clarines, within sight of the Caribbean Sea, interesting fossiliferous limestones are involved in thrust movements along a line of faulting which crosses the Unare River. The fossiliferous content of these limestones is mainly orbitoidal, although the writer has attempted no preparation of sections from his own material. *Lepidocyclina* appears to be abundantly represented, as judged from natural vertical sections in the hand-specimens; Tobler's genus *Helicolepidina* is also reported to be in this locality.

The association of such orbitoidal limestones with typical Eocene sandstones has led naturally to the belief that the limestones are late Eocene in age. Unfortunately, the paleontological evidence is not conclusive. As the phylogeny of the sub-family *Orbitoidinae* is still problematic, the stratigraphic conclusions drawn from it must be doubtful. Under actual field conditions, both near Clarines and at other localities in central Venezuela, the structural relations of the orbitoidal limestones with other sediments are not clear. As thrust faulting is present at all these localities, the normal succession is obscured. From these considerations, and from the abrupt facies change which the orbitoidal limestones represent, the writer is inclined to regard them as belonging to the Oligocene rather than the Eocene period.

Lower Micoene.—The writer knows with certainty only one locality in Anzoategui where Lower Miocene deposits crop out. These occur at a thrust Eocene-Miocene contact where foraminiferal clays are exposed under the thrust north of Piripire shown in Figure 2. Sands with a varied molluscan fauna are superimposed on these clays, and specific determinations of these mollusks may show them to be lower Middle Miocene, or Middle Miocene in age.

Middle or upper Middle Miocene—molluscan Miocene.—The foraminiferal Miocene just described is everywhere overlapped, except north of Piripire, by a shallow-water marine series. This series covers large continuous tracts in northern and central Anzoategui. Cross-bedding may be observed in many places in the series and repetitions of shale-conglomerate bands are also present. These shale conglomerates were presumably formed under quiescent conditions which permitted the washing of clay pellets into sands. The solution of calcareous materials from the sands themselves hardened the pellets, and

FIG. 2.—Reconnaissance geological map of state of Anzoategui, Venezuela.

compaction smoothed them down to the common bedding planes. The result has been to give a typical speckled appearance to the shale conglomerates which is recognizable not only in Anzoategui. but also farther west in large tracts of the adjacent state of Guarico. The shale conglomerates and interbedded sandstones and clays are in many places fossiliferous. The fauna is generally molluscan and the writer would compare it broadly with genera and species from the type Middle Miocene beds of Bowden, Jamaica, British West Indies. The small *Chione walli*, *Cerithium ormei*, *Fasciolaria semistriata*, *Arca trinitaria*, and other forms of Antillean Middle Miocene deposits are present, if one may rely on comparison with figured specimens. The low dips recorded from these beds render it probable that less than 1,000 feet of this molluscan Miocene is exposed despite its broad area of outcrop.

Upper Miocene.—Near San Mateo, it is possible to notice the gradual upward transition of molluscan Miocene into beds of a less consolidated type including massive soft sands and clays. *Foraminifera* were discovered in one of the clay beds by P. A. Spens and the writer, and determination of them showed a species of *Haplophragmoides* similar to specimens in the Upper Miocene of Trinidad.

Elsewhere in Anzoategui, there are beds carrying plant remains whose positions suggest that they too are in the Upper Miocene. In most places, they are even less consolidated than the San Mateo beds and in some places they are distinguished by fine cross-bedding in loose silty deposits.

A separate group of torrential sands and conglomerates together with interbedded clays occurs in hills situated between the Caribbean Sea and the broad outcrop of molluscan Miocene farther south. Steep dips have led certain geologists to propose Oligocene and even Eocene age for this group, but both the steep dips and apparent faults in these hills may be fictitious. It is possible that these sediments were poured into a basin which was being continually and slightly slip-faulted toward the south during deposition. The lack of consolidation of much of the series and the nature of the heavy minerals suggest that the period of deposition for these sediments was at least either late Miocene or perhaps partially in the Pliocene. Thus the mineral suites show an abundance of epidote, soda hornblende, and a few pink garnets. As discussed later, these are essentially later Tertiary residues, closely allied with residues from the molluscan Miocene except for the absence of glaucophane. It is even possible that these Miocene or Mio-Pliocene torrential sediments were partly derived from molluscan Miocene with loss of glaucophane.

Post-Miocene.—South of the latest Miocene deposits in Anzoategui, a thin series of gravels and clays appears. Cementation of the gravels by iron solutions in many places gives a pan-conglomerate in place of gravels, and these pan-conglomerates lie as protective caps above softer sands and clays. This series has no measurable dip, so that pan-protection in many places gives rise to extensive mesas called "llanos" in Venezuela. The beds which give typical "llanos" topography form only a thin veneer and have a maximum thickness of probably less than 300 feet. No fossils from these beds are yet known to the writer.

Recent.—A deposit of loose sand overlies the "llanos" and increases gradually in thickness toward the Orinoco River. The nature of this sand deposit suggests that it is diluvial in origin, and that it was originally laid down by the Orinoco when the course of the river was farther north at the beginning of the present erosion cycle. At certain localities, these loose sands may be more than 100 feet thick.

GEOLOGY

The geology of central and eastern Venezuela is the expression of orogenic movement on the one hand, and of buttress opposition on the other. The results of pressure or upheaval are seen invariably in the northern coastal ranges of such states as Guarico, Monagas, and Anzoategui itself. In a vertical sense, these upheavals have been impressive for they have been sufficient to raise mountain areas which in some places exceed 7,000 feet in height. In a lateral sense, stresses have not been intense when compared with those which elsewhere have resulted in extensive overriding—as in the Swiss Alps. The foothills of these mountain tracts show both metamorphism and thrusting; the metamorphism is definitely not advanced, and the thrusting appears to illustrate the high-angle type. South of the foothills, pressure-release seems to have taken place perhaps with normal faulting, and it is plausible to assume that decrease of pressure should be continuous in a southern sense. There is even ground for belief, that under the southern "llanos" cover, deformation of sediments is so slight as to be negligible. Structures exist under the "llanos" cover, but they may well be of entirely depositional origin with ancient nuclei beneath them. From an oil point of view, such structures may be preëminently promising, and wildcat operations attempting to define them have already shown gratifying results.

Anzoategui conforms with the general north-south picture already given, but is interesting in certain structural modifications which it presents. As in the case of Monagas and Guarico, pressure is evolved in the north and resultant stresses are transmitted southward. In

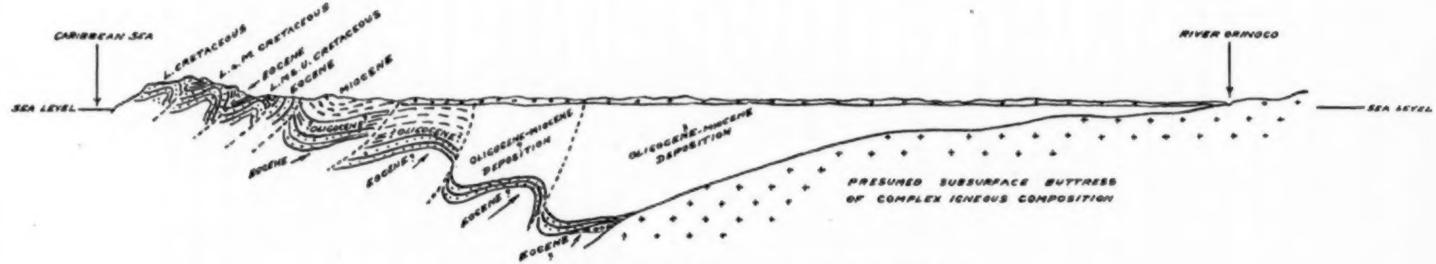

FIG. 3.—Composite north-south section across Anzoategui basin.

addition however, oblique components are brought into play, both in the northeast and northwest corners of the state. In northeastern Anzoategui, structures behind the thrust show a tendency to plunge west and southwest. In northwestern Anzoategui, simple plunge toward the east has taken place in Oligocene fossiliferous limestones, possibly helped by small transverse faults. Thus, plunge in the west, supplemented by opposite plunge in the east, in the latter case with important thrust-faulting as an aid to depression, made a broad basin in northern Anzoategui. It was into this basin that the torrential deposits described as late Miocene or Mio-Pliocene were poured. This exceptional condition is reflected in the trace of the coast line which appears in Figure 2 as a broad indentation. A better idea of the significance of this indentation may be acquired from the state map of Venezuela (Fig. 1).

ANZOATEGUI GEOSYNCLINE

Between the northern foothills of Anzoategui and the southern igneous complex, lies a basin of sedimentation which has been successively filled and broadened from Middle Mesozoic time on. The assumed subsurface topography of the igneous complex as shown in Figure 3 must have been an achieved feature in pre-Paleozoic time, with mountain masses south of the present Orinoco River. Paleozoic sedimentation may therefore have involved transportation of material toward the north. A long positive period is then assumed to have ensued during which Paleozoic sediments were removed from the complex both in central and southern Anzoategui. This removed material was presumably deposited in Mesozoic seas which transgressed as far south as northern Anzoategui. Transport of material to these Mesozoic seas is again pictured as from south to north.

Upheaval in the north and the reverse transportation of sediments must have begun in Mesozoic time. However, this reversal apparently was not important until after the beginning of the Tertiary era. The transportation of material for Eocene seas may have been in a balanced period when waters were supplied from the northern and southern land masses. At the close of Eocene time, however, the northern coastal regions were localities of important orogenic movements. Land masses in these areas may have been of considerable height in Oligocene time and the direction of transportation completely reversed —entirely from north to south. Later Tertiary seas were entirely dominated by these newly risen land masses and the sediments of such stages deposited in waters that were successively restricted as to their northern shore line. In antithesis to this northern restriction,

sediments spread freely along the southern coasts of the ancient complex. Continued sedimentation toward the south resulted in a gradual up-land ascent against the line of the ancient massif until the present Recent infilling against the Orinoco granites and gneisses was deposited.

In some respects, the foregoing reconstruction has been generalized, having certain aspects proper to the adjacent states rather than to Anzoategui. The tendency of Mesozoic and early Tertiary sediments to reciprocal plunge in northern Anzoategui has already been described.

Drop-faulting and oblique thrusting may have accentuated this tendency with the result that a depression was formed with the maximum depth either in late Miocene or Pliocene time. Thus though molluscan or Middle Miocene sediments were elsewhere a normal shore line north of the late Miocene seas, they must be pictured as having formed a peninsula in north-central Anzoategui. On the northern side of this peninsula, torrential deposition presumably took place with late-Miocene or Pliocene conglomerates, sands, and clays. The origin of these sediments is puzzling unless it is assumed that they are from a northern land mass now submerged under the Caribbean Sea. The dropping of land masses north of the Spanish Main under the present Caribbean Sea is frequently adduced as an isostatic adjustment consequent on late Tertiary upheavals on the Main itself. Such considerations however are more pertinent to geodesy than to geology.

The significance of heavy minerals in a reconstruction of the Anzoategui geosyncline is worthy of record. Elsewhere in Venezuela, Illing has made interesting deductions from examination of heavy minerals isolated from his reconnaissance hand specimens. In general, he shows simple mineral suites both for Cretaceous and Eocene as contrasted to richer and more varied suites for the later Tertiary period. For Cretaceous and Eocene, a simple mineral suite is recorded consisting largely of zircon, tourmaline, rutile, ilmenite, and a colorless garnet. Miocene and later rocks show a metamorphic suite including pink garnet, blue hornblende, staurolite, glaucophane, and stable minerals common to the older suites.

In Anzoategui and in Guarico, the writer has recorded similar suites which bear out the distinction between Cretaceous and Eocene sediments on the one hand, and later Tertiary sediments on the other. The blue hornblende and the glaucophane previously mentioned are interesting minerals from a sedimentation point of view. Glaucophane has been recorded from the Miocene of Trinidad and of other coun-

tries, but its abundance in Venezuelan Miocene samples is striking. The mineral was known to exist in the complex massif of the Guayana highlands south of the Orinoco River, but the writer always found difficulty in accepting a transport of material from south to north in Miocene time. Illing has examined some chloritic schists from the northern coast range and has recorded glaucophane in the mineral residues. This is not entirely conclusive support for north-south transport, yet in view of Tertiary coastal orogeny it is significant. Similar support for north-south transport in Miocene time is to be obtained from the presence of blue hornblende in Miocene residues. In molluscan Miocene and in later Miocene residues, the writer finds an amphibole with distinctive blue-green pleochroism. The habit is tabular and almost micaceous and fine biaxial positive figures are obtained. An independent observer has since reported the finding of a blue-green soda hornblende in the complex of an active orogenic belt situated in the coast ranges of central Venezuela. The source of blue hornblende is therefore indicated as being in the north. In the molluscan Miocene particularly, the suites are characterized by a predominance of epidote and glaucophane. Epidote is a somewhat ubiquitous mineral and may also be authigenic in origin. Nevertheless, epidote is known in the northern schists and may be a further indicator of north-south transport in Miocene time.

The inference of these studies is, that Cretaceous and Eocene seas received sediments either from an igneous complex farther south, or from earlier sediments above that igneous complex, one or the other of which may have existed as southern land masses.

Increase or culmination of orogeny in Oligocene time may then have raised land masses which dominated in the north and reversed drainage. The mode of origin of these raised masses favored the formation of metamorphic minerals which were carried southward by later Tertiary drainage to enrich the mineral content of post-Eocene sediments.

GEOPHYSICAL INVESTIGATIONS IN ANZOATEGUI GEOSYNCLINE

The conception of a subsurface buttress of complex igneous composition under the "llanos" of southern Anzoategui has been freely put forward in preceding paragraphs. This conception is based mainly on personal interpretation of geophysical results which the writer has studied. The investigations which gave such results were exclusively seismic methods, both refraction and reflection seismometry having been employed.

The refraction seismic method proved exceedingly valuable in the

information it gave as to the velocity of certain waves in given media. Plotting of routine time-distance curves invariably showed a marked change of gradient between a layer of maximum wave velocity and an overlying layer usually of considerably less velocity. The maximum wave velocity varied between 17,000 and 20,000 feet per second, the medium in which it occurred being generally described as the high-speed bed or basement. Velocities decreased with increasing distance above the basement, and the more pronounced changes of gradient in the time-distance curve above the basement were taken as the loci of formation boundaries above the basement. Interpretations of such formation boundaries may have been somewhat arbitrary since it would not have been difficult to interpret a smooth curve for loci above the basement. Such a smooth curve would be anticipated were there a single formation of uniform lithologic features and naturally increasing density of compaction lying above the basement.

A limitation of the refraction method was encountered when investigations were carried farther out into the main basin of sedimentation. Depths to the basement increased, until at an assumed basement depth of 8,000 feet it was necessary to have the farthest receiver approximately 30,000 feet from the shot-point. Discounting the cost for increased dynamite consumption, energy dispersion was notable over these long wave paths and exact identification of the high-speed or basement wave could not always be exact.

In contradistinction to this limitation of the refraction method, reflection seismography over the same ground showed that depth of penetration to at least 12,000 feet was no great difficulty in field practice. Since the receiver was near or comparatively near the point of explosion, the total wave path for a depth of 8,000 feet was little more than 16,000 feet. For a similar depth in refraction the total wave path of the high-speed wave would be about 46,000 feet. Actually, the reflection method sometimes showed itself sensitive to surface conditions in field practice. In territory where the sandstones and clays of the molluscan Miocene were at the surface, energy conditions were uniformly excellent and reflection traces of high quality were obtained from large areas. In territory where higher ground preserved either the diluvial sands of the present Orinoco River cycle or thicker Pliocene(?) terraces of "llanos" territory, dissipation of energy and loss of penetration were frequent. For reconnaissance work, it was possible to avoid such losses by planning traverses along valleys, but for detailed work, the drilling of shot-holes perhaps to 200 feet might be necessary to overcome the effects of the so-called "weathered zone."

The immense value of the reflection method is its ability to carry quick point-to-point correlation at as close distances as the particular

program may require. According to the conditions of sedimentation at a particular point, the correlation may be carried for as many as seven or eight horizons at once. In fact, the reflection seismogram may be regarded as the geophysical equivalent of a rough well log for each shot location.

In contrast to refraction seismometry, outstanding reflections were not necessarily obtained from a surface at which two rock types of sharply differing density were in contact. Thus the sharp changes of gradient in the time-distance graph of refraction shooting were by no means reproduced sharply on reflection seismograms. Presumably, these differences were partly due to the difference in wave types which the two systems measured. In this connection, it appears that reflected traces are more or less the record of sharp phase changes experienced by the wave train, and perhaps of some little understood type of wave interference. More recently, studies of reflection traces in areas of known subsurface detailed geology indicate that the sharpest reflections are obtained where certain repetitions of lithologic features set up satisfactory rhythms.

In southern Anzoategui, the basement did not everywhere give sharp reflections, but its general homogeneity over restricted areas could usually be recognized, and good correlation was made in the unconsolidated higher formations.

A general decrease of tectonic stress has already been indicated from north to south in the state of Anzoategui. Apparent structures under the southern "llanos" are so gentle, and their relation to the assumed basement so uniform that they may well be entirely depositional in origin, spread above and around ancient anomalies in the basement. It is precisely under these conditions of gentle structure or of deposition that the reflection method is so valuable an exploratory agent. The writer has had no experience with the method in areas of controlled subsurface geology, but it is probable that the physics involved in reflection practice tends to smooth the geological picture. In unconsolidated sediments of low dip or of depositional dip, unconformities are likely to be overlooked, since it has already been predicated that sharp reflection was not necessarily a function of sharp density change.

Knowledge of the two seismic systems leads to the opinion that a comprehensive survey of large areas should include both methods. Refraction leading lines should be laid out for information as to density and velocity of the systems below the surface. Check reflection lines should then follow, together with reflection detail where the results are suggestive.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 246-258, 6 FIGS.

PHYSICAL CHARACTERISTICS OF BARTLESVILLE AND BURBANK SANDS IN NORTHEASTERN OKLAHOMA AND SOUTHEASTERN KANSAS[1]

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ABSTRACT

The Bartlesville and Burbank sands, which occur in the Cherokee shale of the Pennsylvanian series, are composed of quartz grains loosely cemented with a mixture of magnesium, iron, and calcium carbonate, and locally by silica, dolomite, or calcite. The sand commonly contains new quartz growth. Aside from quartz the sand contains ½–2 per cent, commonly 1 per cent mica, traces of feldspars, zircon, chlorite, glauconite, hornblende, rutile, magnetite, pyrite, and epidote, 10–20 per cent detrital rock fragments (chert, shale, and schist), and a trace to 10 per cent of carbonaceous material. Locally, as much as 50 per cent of the sand grains are composed of altered magnetite. Marine fossils were found in the sands and also in thin limestone and shale beds within and immediately above and below the sands.

The sands in most localities are predominantly fine-grained, but locally have a large content of medium and coarse grains and a trace of very coarse grains. The sand in most localities contains 10 per cent silt and clay, but locally the fraction ranges from 5 to 40 per cent. Most of the medium-grained sand and essentially all the finer grains are angular to sub-angular; locally, one-third of the medium grains and, in all localities where present, most of the coarse and very coarse grains are sub-rounded to rounded.

The Bartlesville and Burbank sands are so similar in composition and physical characteristics that they can not be differentiated with certainty although certain differences can be distinguished in sands from two or more specific localities.

INTRODUCTION

More than a year has been spent in a microscopic study of the Bartlesville and Burbank sands in Osage and Kay counties, and a few localities east of Osage County, in Washington and Nowata counties, Oklahoma, and in Greenwood, Butler, and Cowley counties, Kansas (Fig. 1). Most of the work was done on the sands in Osage County. Cuttings from approximately 700 wells were examined. Cores from the sand in the Madison, Edwards Extension, and Quincy fields in Greenwood County, the Haverhill field in Butler County, and the Rainbow Bend field in Cowley County, Kansas, and the Burbank, South Burbank, Pershing, and Avant fields in Osage County, and Coodys Bluff, Delaware, Childers, and Alluwe fields in Nowata County, Oklahoma, were examined.

[1] Read before Division of Paleontology and Mineralogy at Tulsa, March 20, 1936. Manuscript received, November 3, 1936. Published by permission of the director of the United States Geological Survey.

[2] Tide Water Associated Oil Company; formerly with United States Geological Survey, Tulsa, Oklahoma.

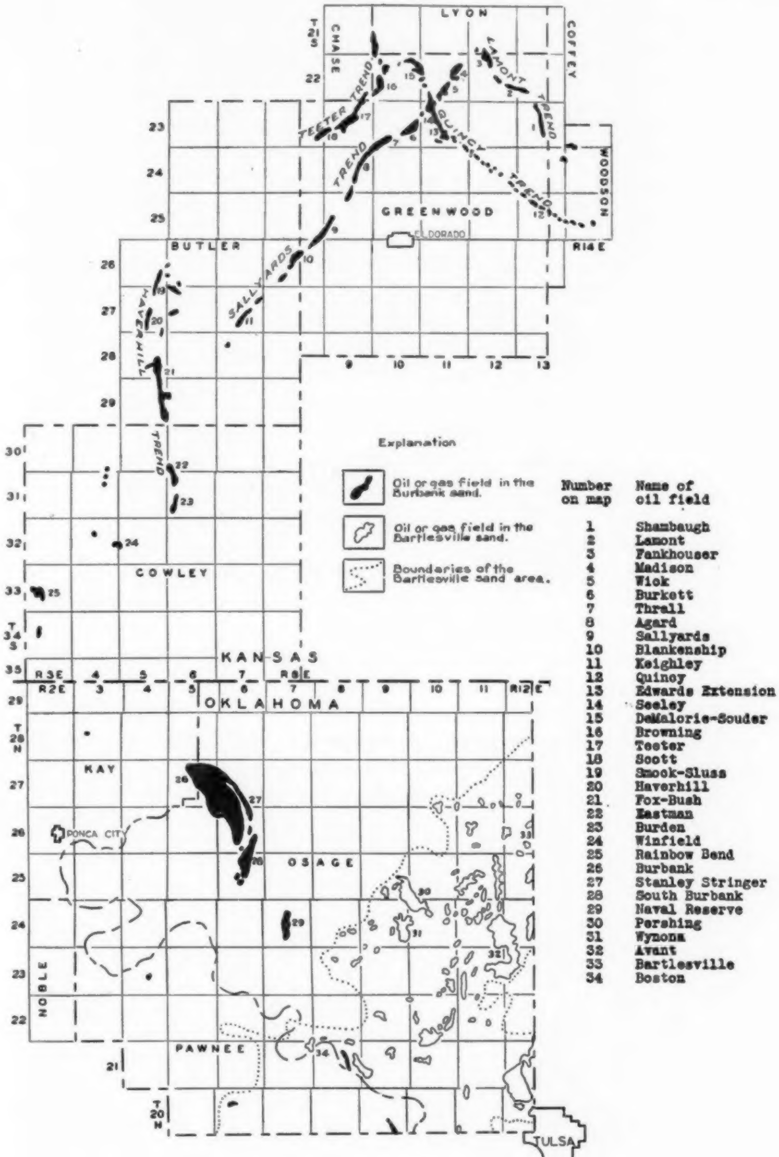

FIG. 1.—Map showing part of region in Oklahoma and Kansas, which contains Bartlesville and Burbank sands.

The study included the examination of outcrop samples from the Moberly, Warrensburg,[3] and Aurora[4] channel sandstones of Missouri, which have been described as sand-filled stream channels of Pennsylvanian age, and the Bluejacket sandstone in southeastern Kansas and northeastern Oklahoma, which is equivalent to a part of the Bartlesville sand.[5]

Samples of beach sands from the barrier beaches of Virginia and from the Pleistocene beaches in the vicinity of the Dismal Swamp of Virginia were examined microscopically and comparisons were made with samples of the channel sandstones of Missouri and well samples of the Bartlesville and Burbank sands in Kansas and Oklahoma. Approximately 150 thin sections of the sands were made from cores of producing wells and from outcrop samples. These were studied with a petrographic microscope.

The studies conducted by the members of the United States Geological Survey party with whom the writer collaborated indicate that the Bartlesville and Burbank sands were deposited as offshore bars, also called barrier beaches, on the western shore of the Cherokee sea which occupied much of northeastern Oklahoma and eastern Kansas. The microscopic study furnished important data that contributed to these conclusions. However, this paper describes only the characteristics of the sands; their origin is discussed in a separate paper by several members of the party.[6]

The combined work of the members of the United States Geological Survey party established to their satisfaction the facts that the Bartlesville sand is older and stratigraphically lower than the Burbank sand, that the Kansas shoestring sands of Greenwood, Butler, and Cowley counties are of approximately the same age as the Burbank, South Burbank, and Naval Reserve sands, and that the Red Fork sand of southern Osage County is approximately equivalent to the Burbank

[3] Arthur Winslow, "The Higginsville Sheet," *Bull. Missouri Geol. Survey*, Vol. 9 (1896), pp. 45–54.
C. F. Marbut, "Geological Description of the Calhoun Sheet," *Missouri Geol. Survey*, Vol. 12, Pt. 2 (1898), pp. 158–59.
Henry Hinds and F. C. Greene, "The Stratigraphy of the Pennsylvanian Series in Missouri," *Missouri Bur. Geol. and Mines*, Vol. 13, 2d Ser. (1915), pp. 95–96.

[4] E. M. Shepard, "Report on Green County, Missouri," *Missouri Geol. Survey*, Vol. 12 (1898), pp. 127–39.
R. B. Rutledge, "Geology of Lawrence County, Missouri," *Missouri Bur. Geol. and Mines*, unpublished manuscript.

[5] L. C. Snider, *Petroleum and Natural Gas in Oklahoma*, Harlow-Ratliff Company, Oklahoma City, Oklahoma (1913), p. 46.

[6] N. W. Bass, Constance Leatherock, W. R. Dillard, and L. E. Kennedy, "Origin and Distribution of the Bartlesville and Burbank Shoestring Oil Sands in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 30–66.

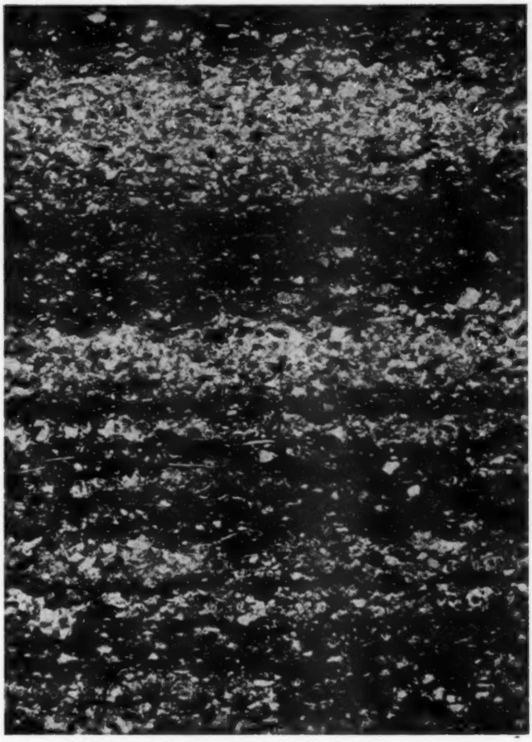

FIG. 2A.—Photomicrograph of thin section from core of Bartlesville sand taken from "break" in sand at depth of about 1,650 feet in W. C. McBride, Inc., well No. 52 in NE. ¼ of Sec. 18, T. 23 N., R. 12 E., Avant oil field, Oklahoma. Light bands are silt and black bands are silty carbonaceous shale. White lines ⅛ inch or less long are mica flakes. (Magnified 25 times; crossed nicols.)

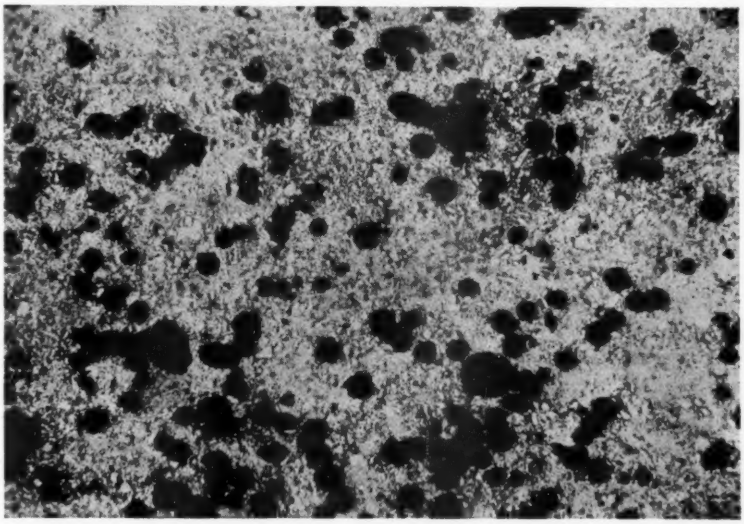

FIG. 2B.—Photomicrograph of thin section from core of Bartlesville sand taken at depth of 631½ feet in Sinclair Prairie Oil Co.'s Viola Bumgarner No. 15 well in NE. ¼ of Sec. 2, T. 26 N., R. 16 E., Nowata County, Oklahoma. Shows siderite concretions in silt matrix. Magnetite centers can not be distinguished in photograph. (Magnified 25 times; direct light.)

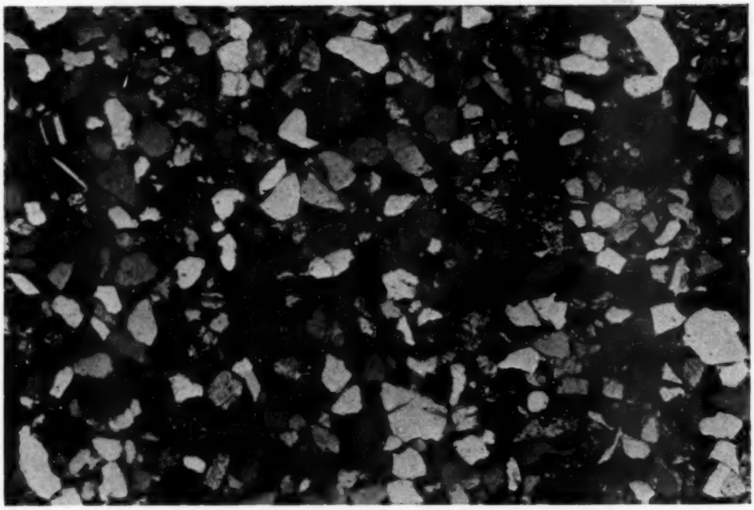

Fig. 3A.—Photomicrograph of thin section made from core of Bartlesville sand taken at depth of 1,536–1,540 feet in W. C. McBride, Inc., well No. 54 in NW. ¼ of Sec. 17, T. 23 N., R. 12 E., Avant oil field, Osage County, Oklahoma. Most sand grains are of fine and medium sizes, angular and sub-angular shapes. Medium-size grain of feldspar occurs about ¾ inch below upper left corner of photograph. (Magnified 25 times; crossed nicols.)

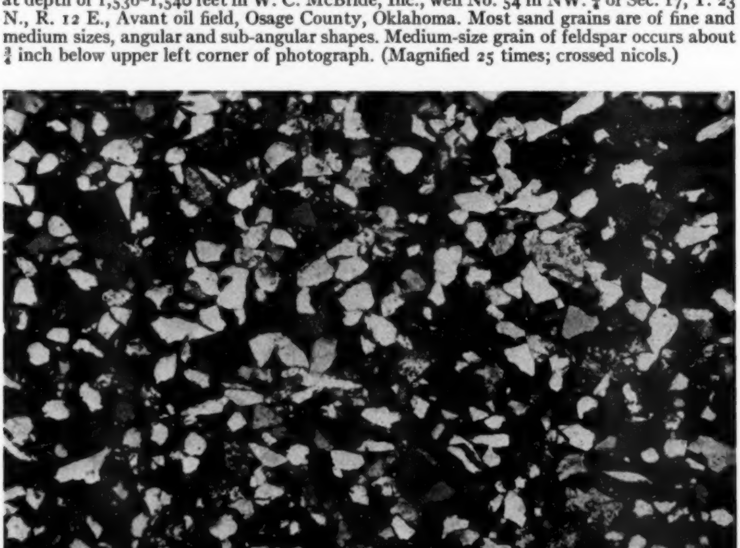

Fig. 3B.—Photomicrograph of thin section made from core of Burbank sand taken at depth of 3,065 feet in Phillips Petroleum Co.'s Rhoads No. 6 well, Sec. 9, T. 27 N., R. 5 E., Burbank oil field, Kay County, Oklahoma. Sand is well sorted, mostly of fine and very fine sizes, and angular and sub-angular shapes. Grains of chert and rock particles other than quartz show as speckled grains. Fairly large stippled area near center of upper right quarter of photograph represents ferrous magnesium calcium carbonate cement. (Magnified 25 times; crossed nicols.)

sand. Therefore, the writer refers to the sand bodies in eastern Osage County and Washington and Nowata counties, Oklahoma, as Bartlesville, and the sand bodies in western Osage and Kay counties, Oklahoma, and Cowley, Butler, and Greenwood counties, Kansas, as Burbank.

REGIONAL CHARACTERISTICS OF SANDS

Cores of the Burbank and Bartlesville sands show that they range from massive beds to finely laminated layers. In the finely laminated parts of the cores the quartz, mica, other minerals, and carbonaceous material are segregated into fine laminae that are sharply defined (Fig. 2A). In some cores the iron-magnesium-calcium carbonate is also segregated in fine laminae. In some cores the bedding appears to be horizontal while cross-bedding is shown in others.

Regionally, the Bartlesville and Burbank sands are remarkably uniform in both composition and texture despite the fact that they are characteristically lenticular. The two sands are so similar in composition and physical character that the writer is unable to differentiate them with certainty although certain differences are discernible when comparing sands from two or more specific localities. However, the differences in the Bartlesville sand at two localities in eastern Osage County where no Burbank sand occurs are commonly as great as the differences between the Bartlesville sand from a specific locality in eastern Osage County and the Burbank sand from western Osage County. Furthermore, differences in texture and even in composition of the sand in different parts of a large oil field are as great as differences found between two sand bodies in widely separated localities. Nevertheless, in certain fields the sand is sufficiently distinctive in composition and physical character to distinguish it from the sand in another field in the same general region. For instance, the Bartlesville sand in the Avant field, in eastern Osage County (Fig. 3A), has several features which distinguish it readily from the Burbank sand in the South Burbank or Burbank fields. The sand in the Avant field is coarser-grained, the grains are not so angular, they show a higher percentage of secondary enlargement, and the sand in general is more friable than that in the Burbank (Fig. 3B) or South Burbank fields.

The Burbank sand in the Madison field (Fig. 4B) in Greenwood County, Kansas, is finer-grained, contains a higher percentage of silt and is less well sorted than the Burbank sand in the Rainbow Bend field (Fig. 5B) of western Cowley County. Likewise the Burbank sand in most of the fields in Greenwood County, Kansas, is finer-grained than the Burbank and Bartlesville sands of most of the fields of Osage County, Oklahoma, with the notable exception of the Naval Reserve

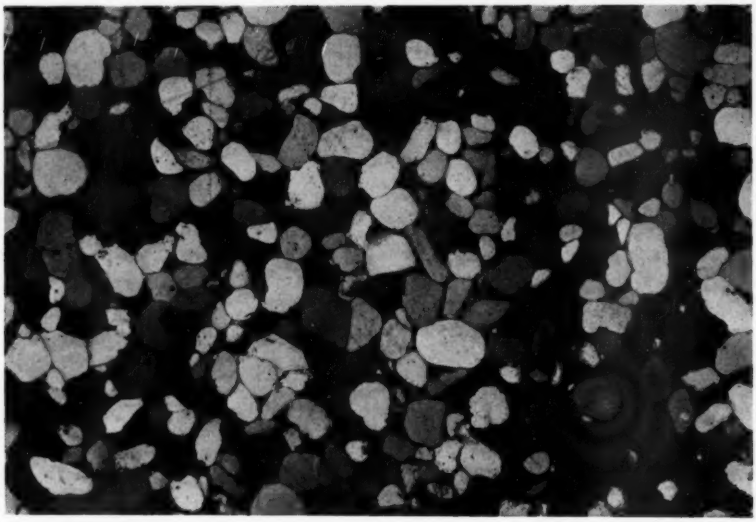

FIG. 4A.—Photomicrograph of thin section made from core of "Second Wilcox" sand from well in Oklahoma City field, Oklahoma, showing mostly medium size, rounded and sub-rounded quartz grains. Almost all sand grains are quartz. (Magnified 25 times; crossed nicols.)

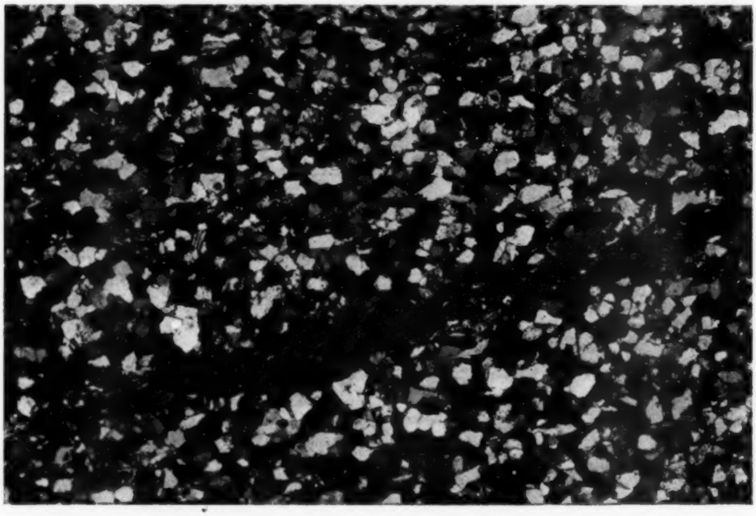

FIG. 4B.—Photomicrograph of thin section from core of Burbank sand taken at depth of 1,846 feet in Empire Oil and Refining Co.'s Kipfer No. 14 well in Sec. 14, T. 22 S., R. 11 E., Madison oil field, Greenwood County, Kansas. Shows predominantly very fine, angular and sub-angular sand grains. Thin bed of black carbonaceous silt crosses lower half of photograph. Striped grain near middle of left half of photograph is grain of feldspar. (Magnified 25 times; crossed nicols.)

oil field where the Burbank sand is as fine-grained as that in any of the Greenwood County fields. The Greenwood County sands have a higher content of silt, clay, and siliceous and carbonate bond, and a higher percentage of secondary enlargement of the quartz grains than the Osage County sands. On the other hand, the Burbank sand of the Quincy field (Fig. 6A) in northeastern Greenwood County is locally composed of coarse, sub-rounded, and rounded grains, and, in fact, grains of this kind are more abundant here than in any other locality examined.

In general, the Bartlesville sand in eastern Osage County has coarser and less angular grains (Fig. 3A) than the typical sand of the Burbank (Fig. 3B) and South Burbank fields in Osage County or than the sands in Cowley County, Kansas (Fig. 5B). Parts of the sand body in the Naval Reserve field are in general unlike any of the other sand bodies in that they consist in the main of very fine-grained sand with which is mixed an abnormally high percentage of silt—as much as 25–30 per cent in the productive part. The examination of samples shows that in general the Bartlesville and Burbank sands outside the oil fields are decidedly finer and more angular, and have a higher silt content than the sands within the fields.

To throw light on the origin of the Bartlesville and Burbank sands, samples from certain outcropping channel sandstones and present-day beach sands were examined. In general, the Missouri channel sandstones (Fig. 6B) are less well sorted than the Bartlesville and Burbank sands from southeastern Kansas and northeastern Oklahoma. The coarser grains are more angular; the sands contain a lower percentage of detrital rock fragments such as schist, shale, and chert.

Samples of sand taken from the wall of a water well in a Pleistocene beach immediately west of Dismal Swamp, Virginia, about 40 feet above the present sea-level, and samples from tidal inlet cut banks in recently formed beaches at Cape Charles and Cape Henry, Virginia, are in general similar in degree of sorting and grain shapes to the Burbank and Bartlesville sands. These beach sands, although generally coarser-grained than the oil sands, are laminated much like the Bartlesville and Burbank sands, and, moreover, the beach sands contain shell fragments, carbonaceous material, carbonized plant fragments, feldspar, and approximately the same content of mica as do the Bartlesville and Burbank sands. Locally, the beach sands have a high content of magnetite which is concentrated in thin laminae. The Bartlesville and Burbank sands contain minute concretions (Fig. 2B) which are composed of siderite with magnetite centers. These concretions, like the magnetite in beach sands, are locally abundant

in certain layers and the writer believes that they were originally magnetite sand grains, similar to the magnetite sand which occurs in present-day beaches, but subsequent to deposition were partially altered to siderite.

Clay balls and rounded chunks of the same material as that which comprises the adjacent marsh muck occur locally in the beach sands. Boulders of shale, most of which are rounded to sub-rounded, were found in the Burbank sand in a core from the Pershing field, in samples from the Kasishke, Kennedy No. 11 well in Sec. 16, T. 24 N., R. 7 E., in the Naval Reserve oil field, and in the so-called Bluejacket sandstone at an outcrop near Columbus in southeastern Kansas.[7]

The results of the examination of samples and cores of the Bartlesville and Burbank sands within and outside the oil producing areas, and the producing and non-producing zones within the oil-bearing sand bodies, show that physical properties of the sand, such as the size, distribution of the grains, and the content of silt and clay, are important factors controlling the yield of petroleum from these sands.

Fossils are very rare in the sand and a careful search was made for the few that were found. Indeterminate shell fragments were found in the sand; and spines, bryozoans, fusulinidae, other foraminifera, ostracods, indeterminate shell fragments, conodonts, and plant material were found in thin limestone beds within the sand, in shale beds within, and immediately above and below the sand. Limestone beds that immediately overlie the Bartlesville and Burbank sands in many localities contain fossils in abundance. These fossils establish the marine origin of the Bartlesville and Burbank sands. The only plant fragments that were identified with certainty were fragments of *Cordaites* leaves and stems. Charles B. Read, paleobotanist of the United States Geological Survey, who identified the plant fragments, stated that the *Cordaites* genus was probably a land plant which grew adjacent to fresh water swamps, but that there is evidence in the material indicating that these plants were killed by saline waters.

COMPOSITION

The Bartlesville and Burbank sands are composed largely of quartz that is in most localities loosely cemented with a mixture of magnesium, iron, and calcium carbonate. The term magnesium siderite or ferrous magnesium calcium carbonate probably fitly describes the cement in most localities. Locally, the sand is cemented with silica, dolomite, and calcite, and the prevalence of new quartz growth suggests that silica forms at least a part of the cement in many parts

[7] W. G. Pierce, U. S. Geological Survey, called the writer's attention to the occurrence of the boulders in Kansas.

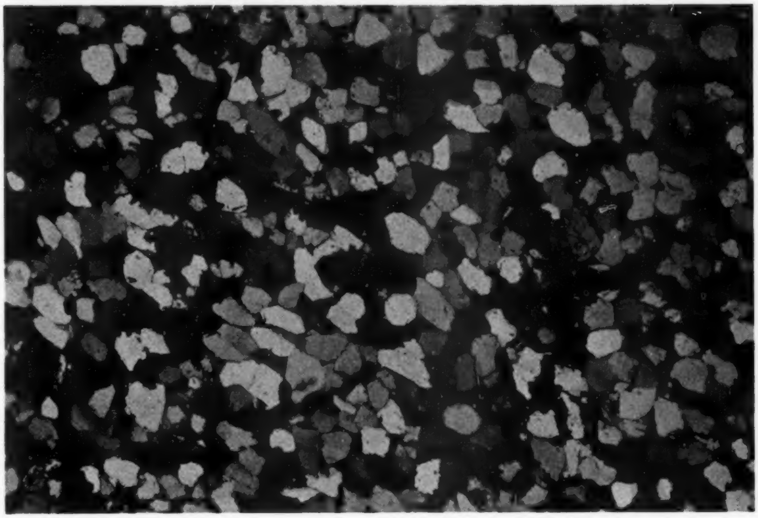

FIG. 5A.—Photomicrograph of thin section of Bluejacket sandstone exposed on Brush Creek, 2 miles southeast of Columbus, Kansas. Sand is composed largely of fine and very fine, angular and sub-angular grains. (Magnified 25 times; crossed nicols.)

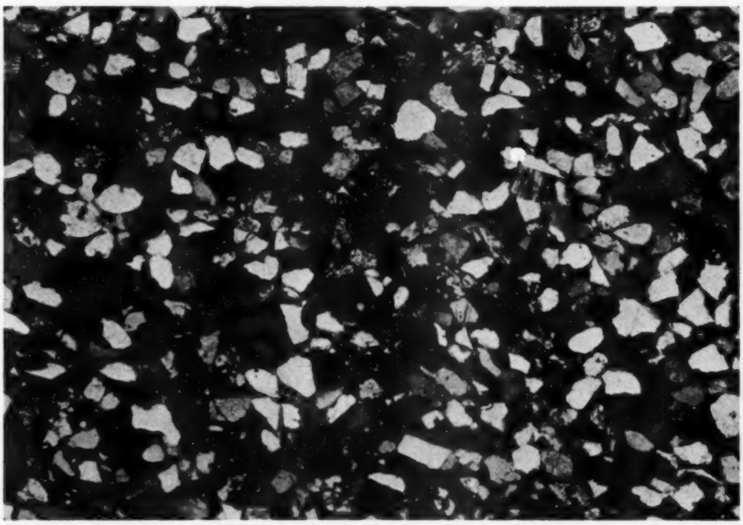

FIG. 5B.—Photomicrograph of thin section from core of Burbank sand taken at depth of 3,268 feet in Barnsdall Oil Co.'s Johnson No. 1 well in SE. ¼ Sec. 20, T. 33 S., R. 3 E., Rainbow Bend oil field, Cowley County, Kansas. Most of sand is fine and very fine, angular and sub-angular, and well sorted. (Magnified 25 times; crossed nicols.)

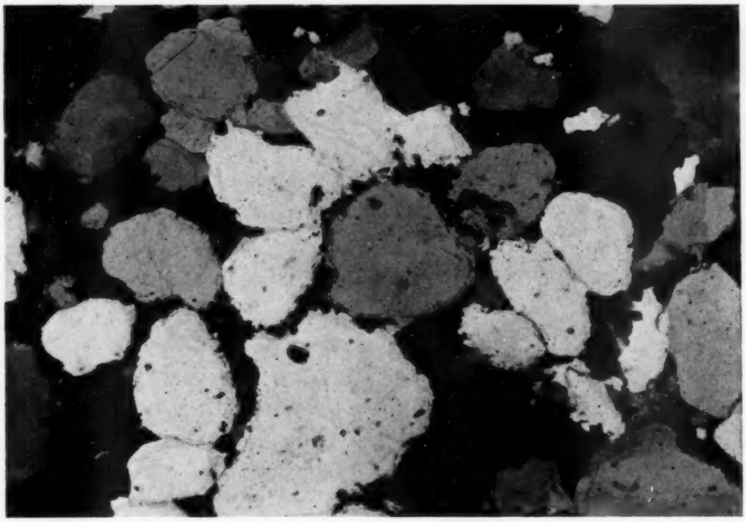

FIG. 6A.—Photomicrograph of thin section from core of Burbank sand from Empire Oil and Refining Co.'s Kolb No. 1 well in Sec. 15, T. 25 S., R. 13 E., Quincy oil field, Greenwood County, Kansas. Rounded and sub-rounded, coarse sand. Irregularly shaped white areas show siliceous cement. Many quartz grains show secondary enlargement which gives margins of grains an irregular outline; dark line inside margin of grain in center of photograph shows inclusions marking boundary of original grain. (Magnified 25 times; crossed nicols.)

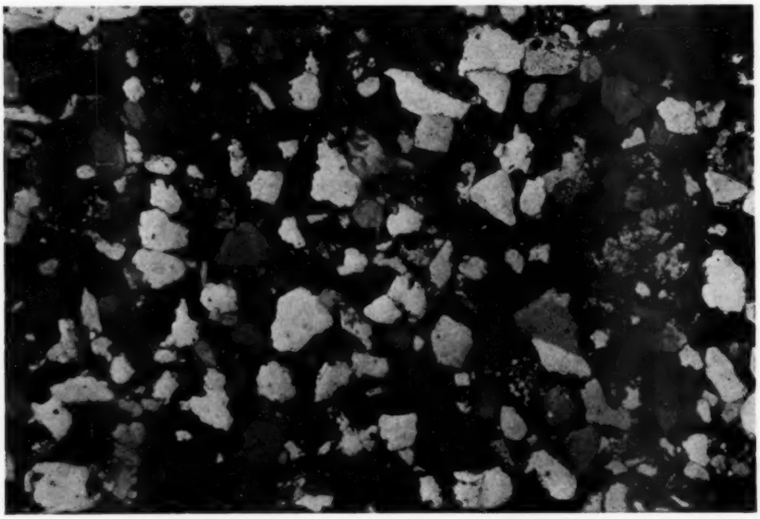

FIG. 6B.—Photomicrograph of thin section of Moberly channel sandstone from Miami quarry, Missouri. Shows poorly sorted angular and sub-angular grains, which range from clay particles to coarse sand. Sand has fairly small content of rock fragments (speckled grains) other than quartz. (Magnified 25 times; crossed nicols.)

of the region. Aside from the quartz the sand contains a small amount, ½–2 per cent, commonly approximately 1 per cent mica—muscovite and biotite.

Traces of feldspar in very fine grains (Figs. 3A and 4B) are present in all localities from which thin sections of the sand were studied and it appears reasonable to conclude that at least a trace of feldspar is present in the sand everywhere in the region. Traces of minerals, such as zircon, chlorite, glauconite, hornblende, rutile, magnetite, pyrite, and epidote, and 10–20 per cent detrital rock fragments (chert, shale and schist), were seen in the thin sections by the aid of the petrographic microscope, but the ordinary examination of cuttings with the binocular microscope did not reveal them. The abundance of rock particles other than quartz in these sands is one of several features which distinguish them from other oil-bearing sands such as the "Wilcox" sands in the Simpson group of Ordovician age, one of which is shown in Figure 4A. The Bartlesville and Burbank sands everywhere contain a trace to 10 per cent of black shiny grains of carbonaceous material that may be coal or asphalt or merely particles of carbonized plant fragments. Some of the carbonaceous particles seen in cores showed definite plant structure.

PHYSICAL CHARACTERS

The Bartlesville and Burbank sands are almost everywhere predominantly fine-grained; that is, the grains range in size from ⅛ to ¼ millimeter in diameter. In all the writer's size descriptions, except that for the silt and clay particles which she included in one class, she has used the classification of C. K. Wentworth[8] which is as follows.

	Size in Millimeters
Boulder	256 or above
Cobble	64–256
Pebble	4– 64
Granule	2– 4
Very coarse sand grain	1– 2
Coarse sand grain	½– 1
Medium sand grain	¼– ½
Fine sand grain	⅛– ¼
Very fine sand grain	$\frac{1}{16}$– ⅛
Silt particle	$\frac{1}{256}$– $\frac{1}{16}$
Clay particle	Smaller than $\frac{1}{256}$

In many localities three-fourths of the sand grains in the Bartlesville and Burbank sands fall into two classes—fine and very fine (Figs. 3B, 4B, 5A, and 5B)—and these two size classes may be said to characterize these sands. Locally, however, they have a larger content of medium and coarse grains, and even a trace of very coarse grains. For example, the sand of the Avant pool (Fig. 3A) in eastern Osage

[8] C. K. Wentworth, "Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. 30 (1922), pp. 377–92.

County and that of a few other localities in southeastern Osage County is composed predominantly of medium sand grains. Locally, in the main Burbank field the sand contains as much as 30 per cent medium grains. In the vicinity of Nowata in the Chelsea field in Nowata County the sand is considerably finer than that of the Avant field but coarser than that in southeastern Osage County. The Bluejacket sandstone on the outcrop (Fig. 5A), like most of the Bartlesville and Burbank sands, is composed predominantly of fine and very fine grains. In most localities the Bluejacket sand contains approximately 10 per cent silt and clay, but in some localities it is cleaner than this. Much of the sand in the Burbank and South Burbank fields contains only about 5 per cent silt and clay but that in the Naval Reserve field and many of the sand bodies of Greenwood and Butler counties, Kansas, contain 20–40 per cent silt and clay. The content of silt and clay in the Bluejacket sandstone on the outcrop is approximately 10 per cent.

Throughout the entire region the fine, very fine, and most of the medium sand grains are sub-angular to angular. Wherever present the coarse and very coarse sand is sub-rounded to rounded. Approximately 30 per cent of the medium sand is sub-rounded. For instance, the sand grains in the Avant field which contains coarser sand than is found in most localities in Osage County are much more rounded than the sand in other localities. Most of the sand in the Quincy field (Fig. 6A) of Greenwood County, Kansas, which is composed predominantly of medium, coarse, and very coarse grains, is sub-rounded and rounded, and the surfaces of the grains have been etched, giving them the appearance of having a thick, frosted coating. In many of the samples containing coarse sand it is difficult to determine the shapes of the grains from the cuttings because of the prevalence of new quartz growth which produces sharp angles and sharply irregular surfaces. However, in thin sections the outlines of the original grains are plainly visible and are marked by dark lines of inclusions (Fig. 6A).

ACKNOWLEDGMENTS

The writer takes pleasure in acknowledging the cordial coöperation of many Mid-Continent oil companies and individual geologists and operators for supplying core and drill samples and other data; of Luther E. Kennedy, Samuel Weidman, and C. S. Ross for aid in the petrographic study; of George D. Gibson who collaborated with her in the early part of the microscopic study of the oil sands; of N. W. Bass and Hugh D. Miser, under whose direction the work was carried on, for many suggestions; of W. H. Bradley for reading and criticizing the manuscript.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 259-267, 1 FIG.

METHOD OF IMPREGNATING POROUS MATERIALS TO FACILITATE PORE STUDIES[1]

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ABSTRACT

An efficient method for the impregnation of porous materials, particularly of low permeabilities, for the purpose of studying the pore system is described. A brief review of previous methods is given, as well as a description of the proposed method and apparatus.

In brief, the method consists of evacuating the air from a clean, dry specimen at room temperature, immersing it in molten balsam, to which an oil-soluble dye has been added, and then forcing that balsam into the evacuated pores under pressure.

The equipment is very simple and inexpensive. It requires only an air-tight cylinder, a means of evacuating it, a method of later applying pressure within it, and a heating unit which will melt the balsam at the proper time.

The pores, as they appear in the resulting sections, are impregnated with the brilliantly dyed balsam, so that a complete study of their size, shape, number, interconnections, and distribution is possible.

INTRODUCTION

The writers, in their various studies of the Pennsylvania oil sands, have found it essential to make a comprehensive study of the pores. Such a study necessitates the observation of the size, shape, and percentage of pore spaces, their distribution and interconnection, and the proportion of the various sizes. In order to accomplish this, it is necessary to impregnate the samples with a material which will show the pore outlines in thin section. Such a material should have a low viscosity and surface tension during impregnation; it should be stable at high temperatures, hard at room temperatures, readily distinguishable from the minerals in thin sections, easily ground during sectioning, hard enough to prevent inclosure of grains of an abrasive, and yet tough enough to eliminate chipping from the pores during grinding. It is also desirable to be able to impregnate several specimens at a time, and to use materials and equipment which are relatively cheap. The methods of impregnation known to the writers and previously used by them did not meet the above requirements to a satisfactory degree, and since reference to the literature disclosed no technique which seemed better, the method here described was developed.

[1] Published by permission of A. W. Gauger, director of research, Mineral Industries Experiment Station, The Pennsylvania State College. Manuscript received, October 13, 1936.

[2] The Pennsylvania State College.

The difficulty of securing perfect impregnations is enhanced in the case of the writers by the extreme "tightness" of the sands which they are studying.

It may be well to add here that this method can be applied, with equally good results, to the preparation of thin sections of ceramic products where it is desirable to study the pores. One of the writers has made numerous sections of bricks, using this method successfully. The filler acts both as bonding material and as a pore indicator.

PREVIOUS METHODS

The writers have used the method developed by Head[3] for making briquets of ore minerals. Bakelite resinoid, used at temperatures sufficiently high to cause melting, is forced into the pores of the specimen with pressure furnished by a hydraulic jack capable of producing a pressure of 7 tons. The difficulties connected with this method are manifold. A maximum of only 2 or 3 specimens at a time can be run in the equipment as designed. The resinoid is very viscous even when melted, and decomposes, with the liberation of ammonia, producing a volume change. It becomes more viscous with the passage of time, and soon ceases to flow. It is often difficult to distinguish it from limonite, or yellow and yellow-stained minerals. If cooked for a sufficiently long time, it becomes a darker brown and looks much like biotite in clayey, fine-grained sands.

Ross,[4] Leggette,[5] and Burgener and Lewis[6] have used bakelite varnish, usually C.V. 1305, for impregnation. The viscosity of the varnish is varied as desired by the addition of suitable solvents, which must later be driven off. Ross accomplished his impregnation at atmospheric pressure, depending on capillary forces and the ability of the material to wet the mineral surfaces. Under such conditions the smaller pores may fail to become impregnated, although it may be possible to secure a bond sufficient to permit easy sectioning. Leggette used a desiccator connected to a pump and produced a partial vacuum. Since his material is immersed in the bakelite varnish before being placed in the desiccator, the air must be forced to bubble out through the varnish, which causes frothing and prevents as complete an extraction of air from the pores as might otherwise be obtained. Bur-

[3] R. E. Head and Morris Slavin, "A New Development in the Preparation of Briquetted Mineral Grains," *Utah Eng. Exper. Sta. Tech. Paper 10* (1930).

[4] Clarence S. Ross, "Methods of Preparation of Sedimentary Materials for Study," *Econ. Geol.*, Vol. 21 (1926), pp. 454–68.

[5] Max Leggette, "The Preparation of Thin Sections of Friable Rock," *Jour. Geol.*, Vol. 36 (1928), pp. 549–57.

[6] Formerly at The Pennsylvania State College.

gener and Lewis mounted their specimen in a low-melting alloy, in a mould which was placed in a suitable pipe fitting, and compressed air was used to force the varnish into the specimen. All these methods require a period of several hours of treatment after impregnation to drive off the volatiles and harden the varnish. This must cause a decrease in the volume of the impregnating medium, which would therefore fail to show any longer the true percentage of pore space present. In addition, the last method cited necessitates even further trouble and delay in mounting the specimens.

Ross also describes the use of balsam and kollolith for impregnation, and Leggette gives reference to an article by Schlossmacker[7] describing a method of impregnating specimens with balsam in a vacuum. The specimen was placed on a shoulder in the container, and after evacuation the chip was caused to fall into the balsam in the bottom of the vessel. The writers, without knowledge of the previously mentioned article, devised a plan very similar in most respects, but more convenient and better suited to the ends to be accomplished. In general, the method here outlined proposes to evacuate the air from a clean, dry specimen, to immerse it in molten balsam, and then to force that balsam into the evacuated pores under pressure.

The use of bakelite resinoid, or varnish, has the advantage of being tough and of not softening when heat is applied during the process of mounting and covering the slip. The last advantage is not shared by Canada balsam. In the case of many sedimentary rocks, such as the oil sands being studied by the writers, and of many ceramic products, there is enough—or nearly enough—cohesion between grains to permit sectioning without a binder. Under such conditions the filler simply designates pore space. The writers have found that balsam can be used both as a binder and a pore indicator if the proper technique is developed in mounting the sections. Porous materials, such as silica brick, which are too friable for grinding, may be bound, sectioned, and mounted, using balsam as the impregnating medium.

IMPREGNATING MEDIUM

Canada balsam in which an oil-soluble dye has been dissolved is used by the writers for impregnation. There is a large variety of colors available for this purpose, but flaming red[8] and deep blue[9] have

[7] K. Schlossmacker, "Ein Verfahren zur Herrichtung von schiefrigen und lockeren Gesteinen zum Dünnschleifen," *Central. für Mineral., Geol. und Paleon.* (1919), pp. 190–92.

[8] Flaming red No. G.-305, Ox Color Works, 140 West 42 Street, New York, N. Y. Also suitable are orange, peacock blue, perfect purple, shamrock green, brilliant green, and sunbeam yellow, all made by the same company.

[9] Du Pont anthraquinone blue, AB base, E. I. du Pont de Nemours and Company, Wilmington, Delaware. Also suitable are yellow, brown, and violet.

proved sufficient for our work. Other colors made by various manufacturers are no doubt available.[10]

Natural paper-filtered balsam is used. This is heated on an electric stove or a flame, and the dye is added to the hot balsam. The balsam should receive enough dye to produce a deep color, since the color will appear much paler in thin section. The dye should be completely dissolved and uniformly distributed by stirring. Heating should be continued long enough so that upon cooling the balsam will be hard and similar in character to that which holds the slip in a thin section.[11] It must not be viscous enough to inclose and hold grains of the abrasive during grinding, nor should it be so brittle that it readily breaks or chips from the pores.

Tests made by the writers indicate that balsam treated in the previously described manner is very satisfactory as an impregnating medium. Balsam of the above character, when remelted, has a surface tension of only 33 dynes per centimeter at 270°F.; 34 dynes at 194°F.; about 36 dynes at 190°F.; and an estimated 45 dynes at 140°F. Its viscosity in the region of 270°F. is about one poise (only about 100 times that of water at room temperature). It is true, of course, that these values will vary somewhat according to the previous treatment applied to the balsam, and that fresh paper-filtered balsam heated for the first time, will show lower values than those just recorded.

Molten balsam was allowed to enter fused quartz capillaries and to come to equilibrium for the purpose of determining whether it would preferentially wet silica. After cooling, the capillaries were examined microscopically and it was found that the balsam-silica contact angle was zero, indicating excellent wetting. Since the great majority of minerals present in rocks and ceramic products are silica or silicates, it is believed that this condition will hold true for these materials also. Thin sections have revealed no instances in which the balsam has failed to wet any mineral type.

MECHANICAL EQUIPMENT

The equipment consists of an air-tight cylinder opening through a small pipe having a T-shaped branch, one branch leading to a vacuum pump and the other to an air compression pump. The cylinder used by the writers has a welded base and a recessed cover which can be

[10] A blue dye, national alizarine blue, G. R. L. base, National Analine and Chemical Company, 40 Rector Street, New York, N. Y., was tried and found satisfactory by the writers, but has not been generally used by them.

[11] The dye should be added after sufficient volatile matter has been driven off to give the proper texture to the resin. The temperature should not be allowed to exceed 300°F. after incorporation of the dye, since this may destroy its color.

drawn down tight against a lead gasket with 5 nuts which screw on to studs welded to the cylinder walls, as shown in Figure 1. This can be constructed from any piece of pipe which has a suitable diameter. The figure shows the equipment as used by the writers, but obviously the dimensions can be changed, in any manner desired, to suit the

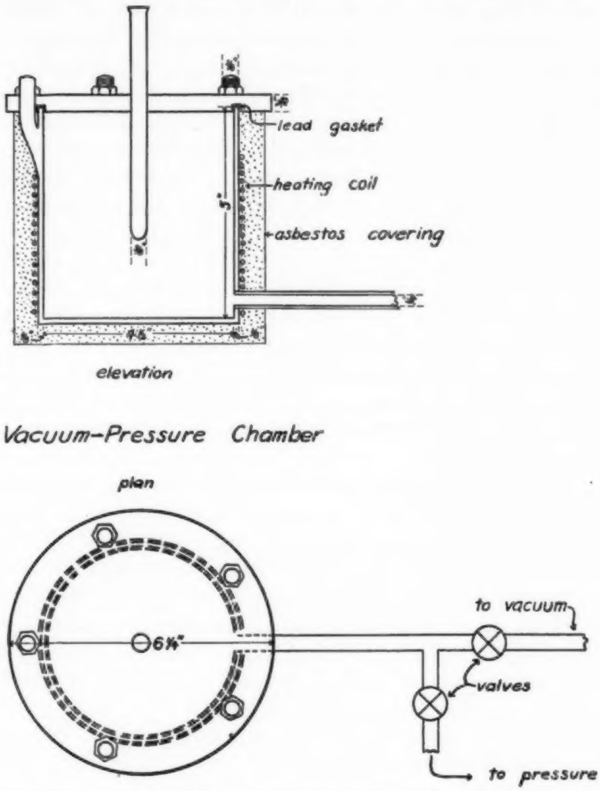

FIG. 1.—Diagrams showing type of equipment used by writers. Dimensions may be changed in any manner desired to suit particular needs of user.

particular needs of the user. The cylinder here shown was used simply because it was already available, having first been designed for another purpose.

The cylinder is wrapped with a layer of asbestos paper, over which is wound electrical resistance wire which is used for a heating unit. This is then completely covered with asbestos for insulating purposes.

A well, constructed of copper tubing of the proper diameter and sealed at the bottom, was welded into the center of the cover. In this was placed the thermometer necessary to indicate the internal temperatures.

The receptacles used to hold the specimens are porcelain crucibles. The writers have found it convenient to use a form 27 millimeters high, 35 millimeters in diameter at the top, and having a capacity of 15 milliliters. Here, also, the size used may be varied to suit the user. Metal receptacles constructed to fit the specimens have also been used. Three layers of these crucibles may be placed in the cylinder here described. This is done by covering the top of each layer of crucibles with an asbestos-covered screen (any fine screen will do). The balsam wets the crucible so efficiently that the molten resin climbs over the edge and may actually drop to the layer below. If sections in the various layers are being impregnated with different colors, a mixing of these colors would be undesirable. The asbestos-covered screen over each layer prevents this. The screen must, of course, be cut to fit the diameter of the cylinder used, and must have a hole cut in the center through which the thermometer well in the cover may pass. Under the conditions already outlined, the writers are able to run 19 specimens at a time, and the equipment could easily be designed to run many more.

The vacuum pump used by the writers is the ordinary laboratory type, capable of reducing the pressure to a millimeter of mercury in a fairly short time. A mercury manometer reading in the range 0 to about 10 centimeters should be used to follow the progress of the evacuation. The valve separating the vacuum system from the impregnation chamber should be placed between the latter and the manometer to prevent blow-outs when the pressure is applied. A similar arrangement should be made on the high pressure part of the line, a bourdon gauge being used instead of a manometer.

The readings on the low- and high-pressure gauges will indicate the extent of impregnation to expect under the operating conditions. Since a change in pressure of one millimeter at these low pressures would have a far greater effect on the extent of impregnation than a pressure of several centimeters when the high pressure is applied, the extent of evacuation should be as low as possible.

The ratio between the low and high pressures measures the efficiency of the process, since it determines the maximum possible reduction in volume of the air in the pores. As an example, the writers shall compare the efficiency of the method proposed in this paper with one which forced a resin into a porous sample under a pressure of 7 tons

per square inch, the initial pressure being atmospheric. Seven tons is approximately 950 atmospheres, so that the reduction in volume is about 950-fold. In the method described in this paper, the pressure was initially one millimeter of mercury and finally 75 pounds or about 3,880 millimeters. This represents a volume decrease of about 3,880-fold. It is obvious, therefore, that on the basis of pressure gradient alone, the present method is 4 times as efficient as the old one.

The pressures used can be varied to suit the convenience and equipment of the manipulator. Even atmospheric pressure applied after a nearly perfect vacuum should produce a good impregnation.

If there is no source of high pressure in the laboratory it might be possible to solder or weld an automobile tire valve to a pipe connected with the system, and to use an automobile pump to bring the pressure up to the desired point.

TECHNIQUE

The specimen is prepared for impregnation by cutting a slip about 2 millimeters thick on a diamond saw, or in some other manner reducing it to a proper size. If the saw is run in kerosene, or in another lubricant, the specimen will absorb some of the liquid. This may be extracted with naphtha, gasoline, or some other suitable solvent.

When the specimen has been reduced to the size desired, it is placed in a porcelain crucible and covered by enough chips of the hard, dyed balsam to cover completely and impregnate the specimen after melting has occurred. If the crucible has been used previously and has a residue of hard balsam in the bottom, the specimen is placed on the top of this and a smaller number of chips placed above.

The crucible is next placed in the cylinder, the top screwed down tight, and a thermometer placed in the well. The vacuum pump is started, and the chamber is evacuated as completely as possible. The writers have been able consistently to reduce the pressure to one millimeter of mercury by using an ordinary laboratory pump. This method of evacuating the sample before it has been covered by the molten balsam is a decided advantage, as the air is readily removed and is not forced to bubble out through a more or less viscous liquid, which not only causes frothing, but also offers resistance to the removal of the air. After the cylinder has reached the minimum pressure (the writers allow 10–15 minutes for this process) the heating unit is connected and the balsam melted. The vacuum pump is kept running until the temperature has reached 150–170°F. At this temperature the balsam will melt down and completely cover the specimen, so that air can no longer be forced into the pores. Air is then allowed to enter

the evacuated chamber and pressure applied. With the pressure on, the temperature is raised to 250°F., and the heating unit is shut off. The temperature may continue to rise after that to nearly 300°F., but should not be allowed to go above that if possible, as it may ruin the color of some of the dyes or may overheat some of the minerals. By allowing the temperature to rise to about 300°F. the viscosity and surface tension of the balsam are reduced to the figures previously listed in this paper, and good impregnation is secured. There is a decided tendency for the balsam to boil, creep up the sides of the crucibles, and run down into the bottom of the chamber at reduced pressures. This both reduces the volume of the balsam in the crucible, which may prevent the specimen from being completely covered, and produces a sticky mess in the bottom of the cylinder. For this reason, pressure is applied at the lowest possible temperature. That temperature is, of course, the point at which the balsam is fluid enough to completely cover the specimen, and to permit no air to enter it. In the equipment used by the writers, this condition was attained at the temperature listed—150–170°F.

After the heating unit has been shut off the specimens are allowed to stand long enough to permit the molten resin to permeate all parts of the specimen, and thus to produce a good impregnation. This time will, of course, vary according to the permeability of the material. The writers, using material having permeabilities of 0.10 millidarcy and less, permit their specimens to stand an hour or more, but specimens removed within half an hour have been found to be well impregnated.

After impregnation, the specimens are removed and allowed to cool. Grinding and sectioning may then proceed in the normal manner. The writers find that the slip should be mounted on the slide very rapidly and removed from the hot plate immediately upon being pressed into place in the hot melted balsam. This prevents heating of the slip, with consequent melting and running of the dyed balsam in the pores. When the cover glass is being mounted, it alone should be placed on the hot plate. The amount of balsam needed for mounting is placed on the cover glass and melted. The cold slide and thin slip are then squeezed down upon the balsam-coated cover glass with firm pressure, and the whole is removed from the hot plate before it can be heated through. The writers are aware of the fact that this rapid mounting does not eliminate bubbles as effectively as could be done by taking more time and heating the slide more completely, which, of course, is possible when bakelite is used. They are convinced, however, that the advantages of more complete impregnation

far outweigh in value any disadvantages resulting from entrapped bubbles.

CONCLUSION

The writers feel that the process outlined in this paper has distinct advantages for the impregnation of materials which are to be used for pore studies in thin section. The equipment is simple and inexpensive and may be used in any laboratory where a vacuum pump is available.[12] It is particularly effective if compressed air is also present. The process is simple and requires a relatively short period for completion, especially when one considers the number of specimens which may be handled at one time. The processes and equipment can be modified easily to suit the needs of the individual case. Finally, it produces well impregnated samples, whose pores are easily and rapidly distinguishable, and it causes no such loss in volume after impregnation as must occur in other processes where volatile solvents have to be removed in order to produce hardening.

[12] Although the writers have not attempted to utilize a water aspirator for the evacuation, it might well be possible to obtain fair impregnations by such a method. A combination of this with the use of an automobile pump for producing pressures, makes this process practicable in any laboratory.

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GEOLOGICAL NOTES

AN APPEAL FOR COÖPERATIVE STUDY OF TIME OF PETROLEUM FORMATION

There is no general agreement among petroleum geologists regarding the time of generation of the natural hydrocarbons as compared with the age of the source materials. One school favors the geologic distillation theory according to which petroleum and natural gas may be generated from organic matter stored in the source beds until temperatures and pressures are raised sufficiently by burial or deformation to bring about the conversion of important quantities of such material. If this theory is correct oil and gas may be formed long after oil shales and other source strata have been deposited, possibly in some cases after the lapse of several geological periods.

Other students of the problem believe that petroleum and natural gas are not derived from organic matter stored for comparatively long periods until conditions favor rapid conversion but are generated essentially as such almost simultaneously with the deposition of the source beds. This interpretation may be designated the contemporaneous theory.

The practical importance attached to the question is obvious to all geologists whose duties involve the problems of oil finding. In the event that it can be demonstrated that oil and gas may be formed early in the history of the source beds then it is apparent that if traps are not already present, deformation of sufficient magnitude to form structural traps must occur during, or soon after, sedimentation if conditions are to be favorable for the concentration of oil and gas into commercial pools in a given area. If, on the other hand, it may be established that oil and gas are formed only after deep burial and incipient metamorphism of the organic matter in the strata, it is apparent that folding long after deposition may afford traps for accumulation.

From the nature of the problem it will probably never be demonstrated that one of these conceptions applies exclusively, yet a careful analysis of a large body of evidence bearing on the time of accumulation should yield data indicating the preponderating importance of one over the other.

The writers, who for several years past have assembled a great deal of information relative to this question, are convinced that many valuable observations concerning the relationship between the time

of formation of petroleum or natural gas and the time of initial development of structural traps have been made by petroleum geologists in local areas that have not been presented in the literature. It frequently happens that an investigator does not have sufficient data on topics of this character to justify publication on the subject, yet the matter may be of great importance to the oil fraternity. An appeal is hereby made to all possessing such data to contribute them to us for study and incorporation in a forthcoming report bearing on the problem. In the final compilation full credit will be given to all authors who have supplied useful information.

F. M. Van Tuyl
Ben H. Parker

Colorado School of Mines
Golden, Colorado
January 4, 1937

THEORY POSTULATING MIGRATION OF OIL ALONG FAULTS[1]

Much has been written on the subject of the origin and migration of oil; in California, until a few years ago, it had generally been assumed that most of the oil originated in organic shales and that later it migrated vertically through the intervening beds into the overlying sands where it is usually found. One of the latest papers on the origin of California oil is by F. M. Anderson,[2] who accepts the old point of view, and expresses the opinion that the bituminous oils probably originated from the diatomaceous shales, and that the oils with a paraffine base came from the foraminiferal shales. Anderson's paper gives a very good review of the literature on the subject.

In recent years a number of geologists have raised the question as to whether oil could migrate vertically across beds. It is pointed out that very commonly oil is found in several distinct zones, one above the other but separated by beds containing very little, if any, trace of oil and in some places these intermediate beds are apparently impervious. Another fact pointed out is that the lowest oil sand may be several thousand feet above the highest organic shale and in such cases the intermediate beds in many places consist of sands full of water that contain very little oil; other intermediate beds of sand may be nearly dry. The question is: if the oil migrated vertically across the beds, why is it that certain permeable sand layers are productive

[1] Read before the Pacific Section of the Association at Los Angeles, November 5, 1936.

[2] F. M. Anderson, "Origin of California Petroleum," *Bull. Geol. Soc. America*, Vol. 37 (1926), pp. 586–614.

while others in between are barren? Would it not seem probable that, if vertical migration took place, the intermediate permeable beds also would contain oil? Why should it not occur in these barren sands, which are as permeable as those in which it is found?

W. A. English,[3] in a paper read before the March, 1928, meeting of the American Association of Petroleum Geologists held in San Francisco and Los Angeles, raised these questions and expressed the opinion that oil does not migrate any great distance vertically but has its origin in the beds in which it is found. The concept allows for lateral, but not for any great amount of vertical migration. Thus, English believes that in southern California, where a large proportion of the oil is found in beds of Pliocene age, the oil originated from the organic matter in those Pliocene deposits and not in the underlying Miocene organic shales.

To the writer it seems more than probable that the organic shales are the chief source of the oil and that there has been vertical migration but not in the way previously thought. The principal reason for believing that the oil originated in the organic shales, outside the organic character of the shales, is that it is never found except in sections where such shales are present. So far as the writer is aware there is no exception to this. As a rule these shales are below the beds containing the oil.

Jenkins,[4] in his paper entitled, "Sandstone Dikes as Conduits for Oil Migration through Shales," accepts the theory that oil is derived from organic shales and postulates that migration through the shales might have been by the way of sandstone dikes.

Several other authors have suggested that migration of oil from lower to higher beds takes place along fissures and joint planes that break across the deposits. One of the latest papers advocating this idea is by Krejci-Graf,[5] entitled, "Ölgeologie als Grundlage einer methodischen Lagerstätten Suche," an abstract of which was recently published by Trask.[6]

The hypothesis proposed by the writer is that a large part of the vertical migration of oil may be accounted for as having taken

[3] W. A. English, "California Petroleum Geology, A Symposium, San Joaquin Valley," *California Oil Bull.* (April, 1928).

[4] Olaf Jenkins, "Sandstone Dikes as Conduits for Oil Migration through Shales," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), pp. 411–21.

[5] K. Krejci-Graf, "Ölgeologie als Grundlage einer methodischen Lagerstätten Suche," *Neues Jahrb. f. Min.* etc. (Stuttgart), Beil. Bd. 73 (1934), pp. 165–210.

[6] Parker D. Trask, "Summary of Recent Foreign Literature on the Problem of Petroleum Generation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 9 (September, 1936), p. 1237.

place along the primary faults that break the old basins of deposition. As has been pointed out in previous papers[7] all major basin areas in the Coast Ranges are broken by faults, most of which had an earlier origin than the sediments which they now cut; in other words, it was the later movements along the faults that broke the overlying sediments. In many places these faults have not broken through the later sediments and are buried at considerable depths. Some of the best examples of this condition are found in the Los Angeles basin. These faults usually represent fairly broad zones of crushing. The water and oil in the lower part of the section, including that in the organic shales, would be under pressure as a result of the weight of the great overlying column of sediments, and consequently, if there should be any passageway of escape, they would be forced into it. The crushed zones of the faults would form such a passageway and the oil and water would be forced up along the fault zone; if the fault had broken through the highest sediments in the section, then probably most of the oil and water would escape to the surface. It is a well known fact that a large proportion of the surface faults that cut the underlying organic shales in the Coast Ranges have asphalt deposits along them.

In the migration upward along a fault the oil would pass into the permeable sands which the faults cuts, above the organic shales. It may be questioned whether very much of it would pass into these permeable beds if the fault zones opened up to the surface for there probably would be less resistance to the flow in that direction; however, if the fault were buried, then the barren sands cut by the fault would offer the best means of escape and the oil and water would be forced into them until they were filled. This would probably take place before the folding; the flat-lying, formerly barren beds would be filled with the oil-laden water under pressure from below. Finally when the folding took place the oil would be segregated in the anticline or in tilted beds against the fault.

By this hypothesis one can account for the fact that the oil sands are in many places more than a thousand feet above the organic shales and separated from them by barren pervious and impervious beds; it also gives us an explanation of why, as is commonly the case, a series

[7] Bruce L. Clark, "Tectonics of the Valle Grande of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 3 (March, 1929), pp. 199–238.

———, "Tectonics of the Coast Ranges of Middle California," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 747–828, Pls. 14–22; 11 figs.

———, "Age of the Primary Faults in the Coast Ranges of California," *Jour. Geol.*, Vol. 40, No. 5 (1932), pp. 384–401.

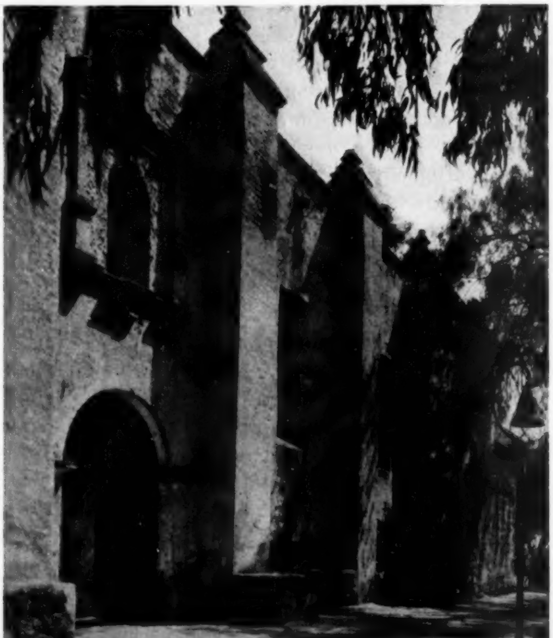
———, "Tectonics of Mt. Diablo and Coalinga Areas, Middle Coast Ranges of California," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1025–78.

of productive sands may be found one above the other separated by pervious but barren sands. In some places, the sands between the productive beds are filled with water which contains very little oil or the sand may be barren of both water and oil.

We may explain the absence of the oil in the water-bearing beds by postulating that the water was in them before they were broken by the fault; thus, when the oil-laden waters were forced up along the fault zone, they could not penetrate the beds already saturated. The absence of both oil and water from the barren beds may be explained as being due to the lenticularity of these beds; they may have been impermeable where they were cut by the fault.

BRUCE L. CLARK

BERKELEY, CALIFORNIA
November, 1936



Courtesy of Los Angeles County Chamber of Commerce

San Gabriel Mission, Los Angeles County

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 273-282

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

**Internationaler Geologen und Mineralogen Kalender (1937)*. Compiled by EDMUND BEYENBURG. Published by Deutsche Geologische Gesellschaft, press of Ferdinand Enke, Stuttgart, Germany (1937). 588 pp. Price, 10 RM.

This book is a most useful world directory of geologists and geological institutions. The first of the two main parts of the book is an address list of 9,000–10,000 geologists. The second part lists by cities, nations, and continents, the state and federal geological surveys, college and university geological departments, geological, mineralogical, and paleontological museums and societies, their series of publications, the staff and rank of each member of the staff for the state and federal surveys, the staff and the rank and specialty of each member of the staff for the college and university geological departments, and the officers of the societies. Dr. Beyenburg seems to have taken many pains to insure high accuracy in his data. The reviewer has found previous editions a very handy book to have on his desk and believes that most geologists and geological institutions will find this a most useful reference book.

DONALD C. BARTON

HOUSTON, TEXAS
December 23, 1936

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*"Contribuções para a Geologia do Petroleo no Reconcavo (Bahia)" (Contributions to the Geology of Petroleum in the Reconcavo, State of Bahia, Brazil). By S. FRÓES ABREU, GLYCON DE PAIVA, and IRNACK DO AMARAL. viii and 232 pp. (Portuguese), 20 pls. (incl. 2 geological sketch maps, 1:1,200,000 and 1:25,000, 1 stratigraphic column, and 35 photographs), 23 figs. (incl. sketch maps, illustrations not numbered). Privately printed by the Tipografia Germania, Franz Timon, Rua da Relação 31, Rio de Janeiro (November, 1936).

Travellers stopping at Salvador, Brazil, commonly called "Bahia," will recall the great elevator that lifted them from dock-level up a steep 200-foot bluff to the "Cidade Alta." This bluff is part of a fault-line scarp that forms the northwestern margin of the gneiss hills along the coast, and overlooks the Reconcavo or interior lowland, which extends about 60 kilometers northwest, with a northeasterly length of more than 150 kilometers.

Most of the lowland is covered by the flat Barreira series (Pliocene continental sands, conglomerates, and clays), which on the island of Santo Amaro, 30 kilometers west-southwest of Salvador, contains a bed of coarse sandstone, 1.4 meters (4.6 feet) thick, impregnated with heavy black oil, of which an analysis is given.

The Barreira series has been swept away from the lower part of the Reconcavo, exposing the Reconcavo series (Lower Cretaceous, continental shales, with subordinate fine-grained, hard sandstone). Vertebrate remains

indicate that the age of the latter is Albian. At Labato, a northern suburb of Salvador, a shallow dug well, about 5 meters deep, penetrated 1 meter of alternating lenses of shales and sandstone, the latter impregnated with about 7 per cent of oil, which may be extracted with solvents. The oil also seeps out of the sandstone into the well, where a few cubic centimeters may be skimmed from the water. Analyses of three samples show densities of 0.850 at 23°C. to 0.900 at 27°C., and a mixed base. The seepage lies on the marginal fault.

The continental Pliocene and Lower Cretaceous strata are regarded as improbable sources of the oil, which the authors believe must have risen from some unknown deeper horizon that fails to crop out. Apparently the exposed strata do not exceed a few hundred feet in thickness, but a much greater thickness is possible, for the lowland has the general form of a basin of deposition, as may be inferred also from the presence of conglomerate in marginal phases of the Cretaceous strata. The probability of a major fault along the southeast margin of the basin suggests further that it may be also a structural basin, but little is known about the structure. Over most of the basin, the Cretaceous strata are nearly horizontal, so far as the authors could determine, excepting numerous examples of contortion from subaqueous gliding, and a few small areas where more regular dips of 10° to 20° were found, and one place where the dip attains 60°. Field observations have not sufficed to delineate structural forms, and it is not certain that they could do so, because of inadequate exposures. In an area of generally horizontal strata, the local occurrence of such high dips suggests to the reviewer that they may be connected with faulting.

The authors conclude that the area is worth further study, preferably with the aid of geophysics, in which the reviewer concurs. The problem seems to call not only for the location of favorable structure, by seismic or other method, but also for the determination of the depth to the crystalline basement, for large oil fields occur generally in basins of thick strata.

In this connection useful comparison may be made with the structural and depositional basin in Patagonia that contains the Commodoro Rivadavia oil field, in which surface studies had indicated the presence of only a few hundred feet of Cretaceous strata, soon proven by the drill to exceed 4,000 feet. It is now thought that the basin contains about 6,000 feet of strata, including supposed "Triassic" strata, in which a new oil horizon has been discovered about 600 meters below the deepest previous production. Pre-Triassic strata, if any, would not be basin deposits, but would be a metamorphosed part of the basement complex. Seismic determination of the true depth of the basin would be of great interest, and possibly of practical significance. Like all the known basins in the area of crystalline rocks far east of the Andes, that of Commodoro Rivadavia seems to lack the great thickness of strata that characterizes most oil-bearing regions. The stratigraphic and structural problems of the Reconcavo basin of Bahia may be expected to be of similar nature.

CHESTER W. WASHBURNE

149 BROADWAY, NEW YORK
January 1, 1937

*"Recherches sur le pétrole dans l'antiquité" (Researches on Petroleum in Antiquity). By A. SEGUIN. *Revue des Questions Historiques* (Paris), Vol. 64, No. 1 (January, 1936), pp. 3–41 Price, 12 Fr.

It has become common-place, when referring to oil deposits in western Asia, to state that they were known since the remotest antiquity and that the Bible mentioned such deposits. Nevertheless, it is not so well known that many other ancient texts cite the existence of oil and its use since the earliest historic time, in these same lands. For this reason the work of a distinguished French archeologist, M. A. Seguin, will be exceedingly interesting to all whose attention has been drawn to these historical problems.

M. Seguin's first article devoted to this matter gives, in the first place, from abundant Latin, Greek, Egyptian, Assyrian, and Hebrew sources, much evidence about the geographic situation of deposits known in antiquity, particularly those of Greece, Mesopotamia, Palestine, Persia, Egypt, and even of the Caucasus, the Indies, North Africa, and Ethiopia.

The second and third chapters indicate the properties and the uses of naft mentioned by the ancient authors. Being inflammable, it was used for illumination, to torture, and in military art, for making incendiary projectiles. It was used in medicine, in embalming, as mortar in construction work, and for caulking ships.

Other articles as a result of Seguin's continued research will doubtless add to our historical knowledge of oil.

H. DE CIZANCOURT

PARIS, FRANCE
October 15, 1936

Stratigraphic Classification of the Pennsylvanian Rocks of Kansas. By RAYMOND C. MOORE. State Geological Survey of Kansas, Lawrence (1936). 256 pp., 12 figs.

This publication is in the nature of a handbook describing the stratigraphic divisions of the Pennsylvanian system of Kansas, "the object being to consider classification and nomenclature of the rocks rather than to portray their stratigraphic development in any detail." With this as an objective, each stratigraphic unit, beginning with the oldest, is described and defined chronologically as it has been used in the literature. Obsolete, abandoned, or not recognized usages are given as well as the present definition. The name of the author, date and publication where first used, and the type locality of each unit are given. These data are followed in each unit by a short description of the lithologic character, physical appearance, and an occasional mention of diagnostic fauna.

The large amount of detailed work which has been done during recent years on the stratigraphic problems of the Pennsylvanian in Kansas is illustrated by the fact that of the 136 valid units described, the usage in 64, or nearly half of the total number, has been first defined since 1930.

The Pennsylvanian-"Permian" boundary is placed at an unconformity occurring above the Brownville limestone and below the Aspinwall limestone, or more than 300 feet below the base of the Cottonwood limestone, the horizon used by the United States Geological Survey as the base of the "Permian." Though the Pennsylvanian is considered in the text as a system, the desirability of adopting the European method is pointed out in the concluding

section of the book. This means the use of the Carboniferous system and the Permian system and in such a classification the Pennsylvanian and the Mississippian would rank as subsystemic divisions of the Carboniferous.

A. I. LEVORSEN

TULSA, OKLAHOMA
January 8, 1937

Einführung in die Geologie; ein Lehrbuch der inneren Dynamik. (Introduction to Geology; a Textbook of Earth Forces.) By HANS CLOOS. xii plus 503 pp., frontispiece, 356 text illus., 3 pls. Gebrüder Borntraeger, Berlin (1936). RM. 24.

For 27 years, Hans Cloos, of the University of Bonn, Germany, has been gathering facts and field observations with regard to the structure of the earth's crust, and the nature of the forces that cause its movements. In this book, he presents his present opinions on the problem.

The two paramount prerequisites to make a treatise of this kind valuable, namely, clear separation of facts and theories, as well as adequate illustration by photos, diagrams, and drawings, are admirably followed, notwithstanding the fact that often a brief statement of fact substitutes for lengthy discussion of thesis and antithesis which have gradually crystallized into the view expressed.

A ten-page introduction leads up to the subject matter which is logically arranged. The first part of the book discusses "The Terrestrial Magma," as the most conspicuous cause of crustal movements (pp. 11–173). "The Crust" takes up the greater part of the book (pp. 177–425), and "The Earth's Interior" is the subject of the last part (pp. 429–481).

The discussion of the feeding channels of volcanoes, which follows that on surface volcanism, leads over to "Subvolcanoes" (pp. 60–66) which have approached the surface to within short distances, doming or fracturing superimposed rocks (laccoliths, bysmaliths, *et cetera*). The main problems connected with true plutonic masses, mode of emplacement, chemical reactions in invaded parts of the crust, and also problems of ore deposition, are followed by discussions on surface form and probable shape of plutons (pp. 66–71). All known types of masses are mentioned, including "pyramidal" ones, with flaring walls, for which the term batholith has been used. Cloos in no way denies the existence of such bodies, although "the imposing substructure can never be followed far "downward" (p. 70).

Various relations between plutonic structures, contact planes, and wall-rock structures allow a structural classification of plutons. They may be concordant, discordant, "konform" (internal flow structures parallel to contacts) or "diskonform," harmonious (internal structure similar to structure of wall rocks) or disharmonious (p. 75).

Magma movements within plutons are inferred from the arrangement of flow structures and such fractures as show a clear relation to flow structures so that the stresses that led to their formation can be deduced.

The chapters on mineralogy and physico-chemistry of igneous rocks, crystallization of magmas, metamorphism, assimilation, differentiation, and economic problems are brief, in view of the scope of the book.

In the introduction to the second part, Cloos outlines what structure studies may attain: (1) accurate observations of the present structure of disturbed parts of the crust, and sequence of deforming movements; (2) recog-

nition of relative ages of various stages or types of movement; (3) suggestions as to most plausible forces to produce observed features; (4) a tectonic synthesis (p. 179). Bending and fracturing, the cardinal forms of deformation, are then introduced.

Folds, uplifts ("Beulen," bumps), and flexures are taken up first. Folds in the strict sense are distinguished from those which are due primarily to vertical forces, and in the mechanical analysis of folds, he distinguishes true folds due to bending, from shear folds, flow folds, and "salt tectonics."

Fractures are grouped into (1) joints, where opposite points on the two surfaces have not been displaced noticeably; (2) fissures, where opposite points have been torn apart appreciably; and (3) slip planes where the two surfaces have slipped past one another.

> Whereas fissures and slip planes give information on kind, direction, and size of tectonic movements, the joints proper record only a state of stress. If we could adopt the concept of purpose, we might say that joints indicate intentions of the crust, whereas the other two show accomplishments (p. 214).

Although the author has made noteworthy contributions to the interpretation of joints, he writes cautiously on another page:

> The joint in the rock, thin as a hair, and straight as a measuring rod, that piece of petrified geometry, promises much, yet discloses little (p. 225).

The discussion of shear joints, tension joints, feather joints, and graben structures is amplified by the author's illuminating experiments with wet clay. The important antithetic movements are duly stressed. Mechanical principles of crustal movements are discussed jointly with Dr. S. Kienow, former Research Associate in the Institute of Applied Mechanics at Göttingen. The diagrams illustrating pure and simple shear and rotational strain are well executed, amply labeled, and the accompanying text is clear and well organized. Various factors which limit the unqualified application of theoretical conditions, such as volume changes, relative movements of adjacent crustal units, inhomogeneity of material, size of reference-unit of mass, are emphasized, and the important observation added that, if a deforming stress acts over extremely long periods of time, the reactions may approach those of true viscous flow, due to relaxation and hysteresis of material under stress (p. 294).

A short, descriptive chapter on earthquakes is followed by another on "tectonic rock metamorphism." Conditions are discussed under which breccias, cataclastic rocks, mylonites, pseudotachylites, slates, and crystalline schists are believed to form. Theories on recrystallization, rock cleavage, rock fabric analyses, and the relations between visible structures and inferred or known directions of maximum rock lengthening are characterized.

In the chapter on "movement and time in the crust," Stille's system of epeirogenic and orogenic movements, evidences of small crustal movements, the significance of unconformities, erosion surfaces, graded bedding, and many other features are taken up, and the subsequent chapters, 12 to 14, outline the characteristics of mountain ranges. Typical examples are singled out for description and illustration. The rôle which plutonic invasions have played in different mountain ranges, is particularly stressed.

Before closing the discussion of the earth's crust, the author gives, in the chapter on "Continental Nuclei and Ocean Basins," a synopsis of the tectonic plan of the earth's crust. An imaginary journey from the Pacific shores

of the New World eastward, 'round the earth, over the drained bottom of the Atlantic, across abysses, plateaus, decken systems, and ancient shields, and with a final glimpse of the polar areas, written with great skill and literary finesse, may do much to show how the wealth of structural detail, amassed and coördinated by the author in this book, creates the basis of an inspiring picture of the development of the earth's crust, in contrast to that of the moon.

In the third part of the book, the methods of gravity determination are outlined, with remarks on problems of isostasy, and hypotheses on the deeper parts of the lithosphere. Geophysical prospecting methods, some of their results, maps of torsion-balance and magnetometric surveys are added. The two concluding sections deal with hypotheses on the earth's interior, and theories of orogenesis and continental genesis.

It is impossible to describe the essential features of this book in a few sentences. In the 481 pages of this treatise, the author has concentrated an immense amount of facts and observations, and in the text illustrations there is incorporated a wealth of information rarely found in any other geological book. The style is grammatically simple, and the sentences usually short, but Cloos' ideology is frequently so unique that American readers may often have difficulty in translating the correct meaning. Perhaps the subtitle of the book is somewhat misleading. This is not a textbook in the ordinary sense of the word; it is the author's analysis of the earth's crust, its structure, and its mechanical evolution. As such, it is an original contribution, and this is reflected also in the text illustrations. There are 124 new ones, of which 34 are elaborate block diagrams, or series of blocks, executed with unusual care. In some respects, the book resembles Bucher's *The Deformation of the Earth's Crust*, yet the two books differ in general plan, angle of approach, and type of discussion.

Although some recent American references and ideas are missing, and students of structural geology may object to the choice, emphasis, or lack of such in the treatment of various topics, and although there are minor oversights in spelling of author names and references, the reviewer has not found any descriptions of facts in which erroneous statements occur. Controversial issues are discussed in cautious, impartial sentences; the author hardly ever discloses where his own mind may take sides. The student of structural problems will find an abundance of references from which he may gather further details necessarily omitted in the condensed treatment of a vast field. Among the few existing compendia that analyze the whole field of tectonics as well as its significant bearings on general, applied, and historical geology, this stimulating book bids fair to remain one of the most arresting ones.

Robert Balk

Mount Holyoke College
South Hadley, Massachusetts
January 15, 1937

"Paläogeographie und Tektonik" (Paleogeography and Tectonics). By Franz Kossmat. Gebrüder Borntraeger, Berlin (1936). 413 pp., frontispiece, 5 pls., 30 text-figs. Price: RM. 18.20, in paper; RM. 20, in cloth.

It is more than a quarter of a century since Professor Kossmat undertook to prepare a volume on paleogeography, but owing to a succession of inter-

ruptions he did not complete it until recently. During this long period, he states, his ideas as to the proper scope of the volume have gradually changed. Instead of staying close to the subject of the geographic distribution of extinct animals—his original field of interest—he has become more and more interested in the relations between paleogeography and the tectonic evolution of the earth's surface. It is this aspect of his work that may make it of interest to many American geologists.

In his introduction, the author classifies the lands into *Kettengebirge*, like the Alps; *Rumpfgebirge*, like the Scandinavian or Ethiopian uplands; *Schichtstufenländer*, like the Russian plains, the Paris Basin or eastern Kansas; *Aufschüttungsebenen*, like the North German or West Siberian plains or the San Joaquin Valley; and *Vulkanlandschaften*, like the Columbia plateau or a volcanic cone. Oceans, he thinks, should be divided into at least four classes: the Pacific, Mediterranean, Atlantic, and Arctic types. His discussion of the development of paleogeography touches many interesting questions, such as the period of time that should be represented on a single paleogeographic map. If the period is very short, he points out, several difficulties are intensified. Since paleogeographic studies have demonstrated that geologic time has consisted of a series of transgressive (thalassocratic) and regressive (epeirocratic) stages, he holds further that the most profitable periods for study are those at which these conditions reached a maximum. Even if it is possible to draw maps for several stages during a thalassocratic stage, the effort may not be much worth while, because it will result merely in showing shoreline changes of the least important type; that is, of the type that results as the sea margin moves back and forth over a broad shelf. The location and shape of the shelf are the important matters, he holds, and not the exact position of the sea margin upon it at different times.

On the classification of geologic processes into orogenic and epeirogenic, Kossmat follows Stille. On page 9 he gives in a table the relation of Stille's orogenic phases to the post-Cambrian "stages" (Stufen) of western Europe.

Kossmat holds that a paleogeographic map should furnish information not only as to the distribution of land and sea but also as to the location of mountain areas of different types and as to the distribution and nature of volcanic processes. He knows of no way to avoid the difficulty caused by the tendency of folding to deform old sea basins and thus change their shape in plan. He considers that a map of the land hemisphere furnishes a reasonably satisfactory base for paleogeographic maps of the world. Of these he furnishes seven examples: one each for Cambrian, Devonian, Lower Carboniferous, Upper Carboniferous, Triassic, Upper Cretaceous, and Middle Eocene.

To illustrate the scale of his discussion it may be interesting to notice the subject-headings in his 22-page account of the Upper Cretaceous. They are:

Upper Cretaceous in North and Middle Europe
Mediterranean Development of European Upper Cretaceous
Continuation of European Upper Cretaceous through Asia
Upper Cretaceous near the South Atlantic Ocean
Upper Cretaceous of the Indian Ocean
Pacific Upper Cretaceous of North America
Atlantic Upper Cretaceous of North America
Mediterranean and Pacific Upper Cretaceous of South America and Antarctica
End of the Mesozoic Era

In the first 275 pages, Kossmat completes his discussion of the different periods and turns next to a 100-page discussion of the "present tectonic plan

of the earth's surface." He starts with the circum-arctic region and works gradually southward to Antarctica. The structure of Eurasia, North America, South America and of some smaller regions is graphically shown on black-and-white maps that are well worth study.

In a final summarizing chapter, the author discusses briefly a number of interesting general questions. Polar asymmetry of the earth, turning points in the earth's history, movements of the crust and attempts to explain them, fluctuations of the sea, tectonics and magma, magma and ore-deposits, geologic distribution of recent vulcanism, and the Mediterranean belt are among the subjects treated in this chapter, at the end of which is a brief summary on the fundamentals of tectonics.

There is a bibliography of about 12 pages and an elaborate table of contents that largely eliminates the need for an index.

RALPH D. REED

LOS ANGELES, CALIFORNIA
January 15, 1937

RECENT PUBLICATIONS

ARGENTINA

"Granulometric Studies in Northern Argentina, with a Short Chapter on the Regional Geology of Central South America," by Tor H. Hagerman. *Geografiska Annales* (Stockholm, Sweden), Vol. 18 (1936). 89 pp., 43 figs., 7 pls. Pt. I, "A Review of the Regional Geology of Central South America," pp. 126–63, Pls. 1–2, Figs. 1–24. Pt. II, "Methodology and the Results of the Granulometric Work," pp. 164–213, Pls. 3–7, Figs. 8–24. 6.75×9.75 inches.

AUSTRIA

*"Erdöl und Erdgas in Oesterreich" (Petroleum and Natural Gas in Austria), by Hermann Vetters. *Bohrtechniker-Zeitung* (Wien), Vol. 54, No. 12 (December, 1936), pp. 271–74; 1 map.

BRAZIL

**Contribuições para a Geologia do Petroleo no Reconcavo, Bahia* (Contributions to the Petroleum Geology of Reconcavo, Bahia), by S. Fróes Abreu, Glycon de Paiva, and Irnack do Amaral. 228 pp., 20 pls., 26 figs. 6.75×9.5 inches. Tipografia Germania, Franz Timon, Rua da Relação, 31, Rio de Janeiro (1936). Paper.

GENERAL

*"Aerial Maps, Greatly Improved, Simplify Work of Geologist and Engineer," by George S. Rice, Jr., in collaboration with James C. Atkinson. *Min. and Met.* (New York), Vol. 17, No. 360 (December, 1936), pp. 569–72; 4 illus.

*"Naphthen- und Methanöle ihre geologische Verbreitung und Entstehung" (Naphthene and Methane Oils, Their Geologic Distribution and Origin), by Hans Hlauschek. *Inst. für Brennstoffgeologie an der Bergakademie Freiberg*, Paper 11 (1937). 147 pp., 14 figs., 39 tables. Ferdinand Enke, Stuttgart.

*"Sedimentation in Relation to Tectonics," by E. B. Bailey. *Bull. Geol. Soc. America* (New York), Vol. 47, No. 11 (November 30, 1936), pp. 1713–26; 3 figs.

*"Stratigraphic Evidence Bearing on Problems of Continental Tectonics," by Raymond C. Moore. *Ibid.*, pp. 1785–1808; 6 figs.

*"Die Aufbereitungsmethoden in Der Mikropaläontologie" (Preparation Methods in Micropaleontology), by C. A. Wicher. *Zeit. Prak. Geol.* (Halle-Saale), Vol. 44, No. 11 (November, 1936), pp. 174–76.

Paläogeographia und Tektonik (Paleogeography and Tectonics), by Franz Kossmat. 414 pp., 5 pls., 30 figs. 6.5×10 inches. Gebrüder Borntraeger, Berlin (1936). Price: paper, RM 18.20; cloth, RM 20.

KANSAS

Kansas Oil. Published by *Ira Rinehart's Oil Report*, Arthur Davenport, editor, Floyd Swindell, statistician. 176 pp. Contains 12 pool maps and a general state map showing pools and pipe lines. Lists 168 western Kansas pools with statistics. Production table. Rinehart Oil News Company, Daniel Building, Tulsa, Oklahoma (November, 1936). Price, $7.50.

NEBRASKA

*"Nebraska's Chances for Finding Oil Improving," by Kent K. Kimball. *Oil and Gas Jour.* (Tulsa), Vol. 35, No. 31 (December 17, 1936), pp. 13 and 14; 4 illus.

POLAND

*"Problemat rezerw gazu ziemnego w Polsce" (The Problem of the Reserves of Natural Gas in Poland), by K. Tołwiński. *Ann. Soc. Geol. Pologne* (Kraków), Vol. 12 (1936). 55 pp., 2 maps, 16 figs. Summary in French by St. Krajewski and A. Cailleux.

WASHINGTON

*"Preliminary Report on Petroleum and Natural Gas in Washington," by Sheldon L. Glover. *State of Washington Dept. Conservation and Devel.* (Olympia), *Rept. Invest. 4* (1936). 24 pp., 1 map, 5 tables, bibliography.

WYOMING

"Oil and Gas Map of Wyoming." Issued with *Inland Oil Index* (Casper, January 1, 1937). One sheet, 27×21 inches. Shows oil and gas fields, unproved structures, pipe lines, refining centers, highways. Separate copies for sale by *Inland Oil Index*, Casper, Wyoming. Price, 10 cents.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Fort Worth, Texas), Vol. 6, No. 3 (December, 1936).

"The Size Distribution of Minerals in Mississippi River Sands," by R. Dana Russell.

"Petrography and Distribution of a Highly Weathered Drift in the Kansas River Valley," by W. Farrin Hoover.

"Determination and Calculation of Sphericity Values of Pebbles," by F. J. Pettijohn.

"The Method of Moments" (discussion), by Chester K. Wentworth.

"Rejoinder to Wentworth's Discussion of the Method of Moments" (discussion), by K. C. Krumbein.

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 8 (December, 1936).

"Pennsylvanian Fusulinids from Ohio," by M. L. Thompson.

"A New Permian Ammonoid Fauna from Western Australia," by A. K. Miller.

"Ostracoda of the Genera *Eucythere, Cytherura, Eucytherura and Loxoconcha* from the Cretaceous of Texas," by C. I. Alexander.

"Shell Structure of the Ostracode Genus *Cytheridea*," by Morton B. Stephenson.

"Carboniferous Trilobite Genera," by J. Marvin Weller.

"The Casper Formation (Pennsylvanian) of Wyoming and Its Cephalopod Fauna," by A. K. Miller and H. D. Thomas.

"Ostracodes of the Silica Shale, Middle Devonian, of Ohio," by Grace A. Stewart.

"Structural Trends of the Trochiliscaceae," by Raymond E. Peck.

"Carboniferous Ostracodes," by Betty Kellett.

"Occurrence of *Nonionella cockfieldensis* at Claiborne, Alabama," by J. B. Garrett, Jr.

Biltmore Hotel, Los Angeles, California
A.A.P.G. headquarters, March 17–19, 1937

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937), PP. 283-286

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualification of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Tracy Gillette, New York, N. Y.
Quentin D. Singewald, Joseph T. Singewald, Jr., William B. Heroy
Kenneth Washington Gray, London, England
George M. Lees, F. E. Wellings, W. G. Woolnough
Hubert Guyod, Houston, Tex.
L. W. Storm, P. Charrin, Paul Weaver
Curtis R. McKnight, Shreveport, La.
Albert E. Oldham, E. L. Caster, Sidney A. Packard
George L. Richards, Jr., Altadena, Calif.
W. D. Kleinpell, Eliot Blackwelder, Chester Cassel

FOR ASSOCIATE MEMBERSHIP

Jules Braunstein, New York, N. Y.
H. N. Coryell, Earl Emendorfer, G. M. Kay
Clarence Eckhardt Brehm, Tulsa, Okla.
E. A. Wyman, John L. Ferguson, Jess Vernon
Charles Hatton Coldwell, Tyler, Tex.
F. E. Heath, James A. Waters, F. H. Lahee
Rodman Kay Cross, Bakersfield, Calif.
H. W. Hoots, Louis N. Waterfall, E. R. Atwill
Fred Holmsley Moore, Midland, Tex.
Fred H. Wilcox, S. A. Thompson, Gayle Scott
A. Lyndon Morrow, Wichita, Kan.
E. P. Philbrick, F. E. Wimbish, Anthony Folger
W. Layton Stanton, Jr., Bakersfield, Calif.
Desaix B. Myers, Harold W. Hoots, Louis N. Waterfall
Howard Lee Tipsword, Tulsa, Okla.
Dollie Radler Hall, Bruce H. Harlton, V. H. Welch
Richard Daniel White, Houston, Tex.
Gage Lund, Carey Croneis, D. Jerome Fisher

FOR TRANSFER TO ACTIVE MEMBERSHIP

Bob Hancock, Bartlesville, Okla.
Clare M. Clark, Homer H. Charles, W. M. Stirtz

TWENTY-SECOND ANNUAL MEETING, LOS ANGELES MARCH 17, 18, 19, 1937

Plans for the twenty-second annual meeting have been announced from month to month in previous numbers of the *Bulletin*, and in mailed announcements to each member. The technical program is scheduled on Wednesday, Thursday, and Friday, March 17, 18, and 19, so as to leave the week ends free for travelling if members coming from a distance care to save office time in this way. However, the local committee is arranging sight-seeing excursions and field trips so that the full week, and longer if desired, can be well spent in Los Angeles and the surrounding region. As usual, the day before the official opening of the convention will be a day few will care to miss, Tuesday, March 16; it will afford time to meet friends before the scheduled program; it will be a busy day for officers and district representatives who will direct the business sessions; and at night it will be the meeting time of the round-table discussion of the research committee.

Donald C. Barton, chairman of the research committee, announces a meeting for Tuesday forenoon. The annual dinner of the research committee will be held at 6:45 on Tuesday evening, March 16, before the opening of the general meeting of the Association. The annual open discussion meeting of the research committee will follow immediately after the dinner. Both the dinner and discussion meeting are open to the members of the Association or to any other scientist who can contribute pertinently to the discussion. The key topic will be: "The Origin of Oil." The leader of the discussion will be Parker D. Trask. A series of key topics which constitute the more important aspects of the problem have been outlined by Trask (October *Bulletin*, pp. 1380–1). The members of the audience should be prepared to be quizzed in regard to their opinion on those topics and in regard to their opinion on the question of how much opinion oil geologists are entitled to have on those topics on the basis of the available data.

Frank A. Morgan, Rio Grande Oil Company, 855 Subway Terminal Building, is general chairman of the arrangements committee. The convention headquarters is the Biltmore Hotel.

Harold W. Hoots, Union Oil Company of California, chairman of the technical program committee, announces the following tentative list of the authors and titles of papers that appear to be assured.

Presidential Address by Ralph D. Reed

CALIFORNIA	
Ralph D. Reed	The Geologic Setting for California
Drexler Dana	Historical Development of California Oil Fields
Sam Grinsfelder and W. S. Eggleston	Geology of the Dominguez Oil Field
James M. Kirby	Geology of Sacramento Valley
WASHINGTON AND OREGON	
Chas. E. Weaver	Geology of Washington and Oregon
ROCKY MOUNTAIN REGION	
Joseph Neely	Distribution and Character of the Sundance Formation
R. L. Heaton	Relation between Stratigraphy and Structure as regards Oil Accumulation in the Rocky Mountain Region
Harry W. Oborne and W. O. Thompson	Geology of the Front Range and Adjoining Region
John Bartram	Upper Cretaceous of the Rocky Mountain Region
KANSAS	
E. A. Koester and J. I. Daniels	Regional Paper on the Geology of Kansas
?	General Paper on the Geology of Rice and Ellsworth Counties

OKLAHOMA

N. W. Bass	Verden Sandstone of Oklahoma
Bruce Harlton	Ouachita Mountains
P. E. Fitzgerald and W. Wray Love	The Importance of Geological Data in the Acidizing of Wells

TEXAS

E. G. Thompson	Fault System of Northeast Texas with Emphasis on the Talco Structure as a Type
Herschel H. Cooper	Occurrence and Accumulation of Oil in the Laredo District of Texas
Phillip F. Martyn	Geology of the Refugio Field
E. Russell Lloyd	Geology of the West Texas Permian
John Emery Adams	Permian Sedimentation in West Texas and New Mexico
P. D. Moore	Pre-Permian Stratigraphy of West Texas

LOUISIANA AND ARKANSAS

Max Bornhauser	Geology of the Tepetate Field
R. T. Hazzard	Oligocene-Miocene Problem in Louisiana and Arkansas

ILLINOIS

J. M. Weller and A. H. Bell	Geology of the Illinois Coal Basin

FOREIGN

J. O. Nomland	Geology of Bahrein Island
J. S. Irwin	Oil and Gas Possibilities of Western Canada
W. B. Heroy	Recent Developments in Foreign Countries

GENERAL PAPERS

Frank Rieber	Motion-Picture Presentation of Reflected-Wave Pattern from Various Geological Structures
L. W. Blau	Recent Progress and Future Outlook of Geophysics
Wallace E. Pratt	Discovery Rates in the Search for Oil Fields
John L. Rich	Application of the Principle of Differential Settling to the Finding of Lenticular Sand Bodies
D. C. Barton	Variations of Crude Oil in Texas (or the United States)
O. L. Brace	Interrelationship of Geology and Geophysics
E. D. Lynton	Orienting Cores by their Magnetic Polarity
E. DeGolyer	The Future of Petroleum Exploration
W. L. Cozzens	Latest Developments in Aerial Photographic Mapping

PAPERS ON RECENT DEVELOPMENTS

California	
Foreign Countries	W. B. Heroy
Rocky Mountain Region	A. E. Brainerd and C. S. Lavington
Kansas and Nebraska	G. W. Baughman and Marvin Lee
Oklahoma	Ira Cram
West Texas and Southeast New Mexico	Hal P. Bybee
Southwest Texas (including San Antonio district)	Harry H. Nowlan
North Texas and the Panhandle	Albert W. Weeks
East and Northeast Texas	Wallace Ralston
Gulf Coast of Texas and Louisiana	O. L. Brace
Northern Louisiana and Arkansas	

General Symposium on Micropaleontology and Stratigraphy of California Cretaceous and Tertiary (see page 292 for later announcement)

Merle C. Israelsky	Notes on Marysville Butte Foraminifera
W. P. Woodring	Paleogeographic Implications of Larger Fossils from the Repetto Formation of the Los Angeles Basin
Marcus A. Hanna and Donald Gravel	A New Lepidocyclina Horizon in the Heterostegina Zone of the Upper Oligocene of Texas and Louisiana
Charles Canfield	Stratigraphy and Paleontology of the Santa Barbara Valley Field, Santa Maria, California
H. H. Bradfield	New Names for Pennsylvanian Ostracoda (by title)
H. L. Durgan	Species of the Genus Cytheropteron from the Weno formation (Middle Washita) of Southern Oklahoma and Northern Texas (by title)

ASSOCIATION COMMITTEES

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Memorial

ROBERT MASSIE WHITESIDE

(1895–1936)

Robert Massie Whiteside was born in Carthage, Missouri, December 17, 1895, and received his early education in various schools of southeastern Kansas, Missouri, and the state of Washington.

Prior to 1917 he was employed by his father, H. H. Whiteside (deceased) in zinc smelting and oil and gas exploration in Kansas. He was in the United States Army from April, 1917, to December, 1918, attaining the rank of Second Lieutenant. During the period 1918 to 1920 he was employed by the United States Shipping Board in New York. From February, 1922, to October, 1923, he was employed by the Sinclair Oil and Gas Company, Tulsa, in surface and subsurface geology. He was engaged in independent surface and subsurface geology in Cherryvale, Kansas, from September, 1923, to April, 1924. From 1924 to August, 1929, he was again in the employ of Sinclair Oil and Gas Company, this time as paleontologist and stratigrapher. In August, 1929, he joined the exploration department of the Shell Petroleum Corporation in Oklahoma City and Tulsa as stratigrapher and continued in that position until March, 1936, when he left to enter the oil business for himself. His first venture around the Grapeland prospect, Houston County, Texas, seemed successful, and he was engaged in developing these interests at the time of his death.

Bob's energy and natural ability are attested by the fact that he did not receive university training or any schooling in geology, yet achieved a place in the study of Paleozoic stratigraphy. He was one of the few persons to receive the honor of membership in the American Association of Petroleum Geologists without having had college training. He was also a member of the Paleontological Society of America, Tulsa Stratigraphic Society, and Tulsa Geological Society. Many long and tedious hours day and night were spent in grooming himself for stratigraphic and paleontological work in both the field and laboratory. In this he exhibited a remarkable tenacity of purpose.

Worthy of especial note are Bob's contributions to the taking and study of drill cuttings, two papers on which were published in the *Bulletin* of the American Association of Petroleum Geologists; also, the many surface sections sampled, which to-day are standards for certain portions of the Mid-Continent for several of the major companies.

In August of 1928 he was married to Katherine Miller, who with one son, Robert, aged 2 years, survives him. He is also survived by Mrs. H. H. Whiteside of Seattle, Washington, and two brothers, Harlow, also of Seattle, and Allen, of Tulsa.

In the summer of 1936 Bob received injuries in an automobile accident from which he never fully recovered. These injuries led him into ill health and he died, November 19, 1936, in Dallas, Texas.

FREDERIC A. BUSH

TULSA, OKLAHOMA
January 9, 1937

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 2 (FEBRUARY, 1937) PP. 288-292

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

A. F. MORRIS has been appointed chief geologist of the Empire Oil and Refining Company, filling the vacancy made by the resignation of J. M. NISBET. ROBERT L. KIDD has been made assistant chief geologist.

H. R. KAMB has been made district geologist in the Louisiana-Arkansas office of the Shell Petroleum Corporation in Shreveport.

LON TURK, consulting geologist, who recently completed a survey of the Oklahoma City field, discussed that area in a lecture at a special meeting of the Oklahoma City Geological Society. Slides and maps were used. The lecture was open to visiting oil men attending the Independent Petroleum Association meeting.

RICHARD WERNER of Fort Worth, Texas, mechanical engineer, born and educated in Germany, addressed the Forth Worth Geological Society, December 3. He has just returned from Germany and spoke on "Germany of To-Day."

E. M. CLOSUIT, formerly of Dallas, is now a member of the firm, Murchison and Closuit, Inc., Alamo National Building, San Antonio, Texas.

L. G. HUNTLEY, of Huntley and Huntley, Pittsburgh, left New York, November 18, for several months' professional work in Europe.

C. W. SANDERS returned from The Hague in December and may be addressed in care of the Shell Petroleum Corporation, Shell Building, Houston, Texas. While in Europe he visited oil fields and studied salt structures in Germany and Roumania.

DANA HOGAN, president of the Hogan Petroleum Company, was elected chairman of the Wildcat Committee of the California Oil and Gas Association; FRANK MORGAN, vice-president of the Rio Grande Oil Company, vice-chairman; J. R. PEMBERTON, oil umpire of California, treasurer.

LELAND W. JONES, of the Ohio Oil Company, has been elected president of the Oklahoma City Geological Society. E. A. PASCHÁL, of the Coline Oil Company, was elected vice-president and HARRY E. CROCKETT, consulting geologist, secretary-treasurer.

M. ALBERTSON, Shell Petroleum Corporation research engineer, Houston, has been appointed chairman of a study committee on well spacing by the American Petroleum Institute division of production.

EDGAR D. KLINGER, consulting geologist, San Angelo, Texas, has been appointed chief geologist for the Lion Oil Refining Company, El Dorado, Arkansas, succeeding MALCOLM E. WILSON.

RUBE COTULLA, San Antonio, has resigned from the geological department of the Windsor Oil Company, to enter the consulting field.

E. H. FINCH, of San Antonio, Texas, has returned to the States after several months' geological work in Cuba.

J. L. MATHIEU, of the Schlumberger Well Survey Corporation, Houston, Texas, addressed the Fort Worth Geological Society, December 10. He discussed the Schlumberger surveys in wells of West Texas and southeastern New Mexico.

P. M. BIRDSONG has recently become assistant in the West Texas geological department of the Plymouth Oil Company. His address is Box 575, Texon, Texas.

GEOFFREY JEFFREYS is in the geological division of the Southern Natural Gas Company, Watts Building, Birmingham, Alabama.

THOMAS F. STIPP has accepted a position as petroleum engineer with the United States Geological Survey, Federal Building, Casper, Wyoming.

BENO GUTENBERG, professor of geophysics and meteorology in the California Institute of Technology, gave an illustrated lecture on "Earthquakes" before the chapter of the Society of Sigma Xi of the University of California at Los Angeles, December 2.

GEORGE OTIS SMITH spoke at a joint meeting of the Gulf Coast Section of the American Institute of Mining and Metallurgical Engineers and the Houston Geological Society in the Houston Club, December 18.

F. E. MARSHALL, formerly geologist for the Signal Oil Company is now with Snowden and McSweeney Company, Fort Worth. He is in charge of a new district office in Wichita, Kansas.

OSCAR HATCHER, formerly chief geologist for E. H. Moore, Inc., resigned to become a consulting geologist. He will continue to make his home in Ada, Oklahoma.

WESLEY G. GISH has resigned as head of the land and geological departments of the southern division of the Sinclair Prairie Oil Company to become vice-president in charge of exploration and director of the Transwestern Oil Company, Colcord Building (Box 1966), Oklahoma City, Oklahoma. E. L. DEGOLYER is a director of the Transwestern Oil Company.

B. F. HAKE, division geologist for the Gulf Oil Corporation in Michigan, recently gave an address on "Exploring the Field of Geological Argument" at the organization meeting of the Central Michigan Geological Society.

E. L. PORCH, of San Antonio, Texas, is resident geologist for the Fullerton Oil Company and CLAUDE V. BIRKHEAD is Texas manager of the company.

The Fort Worth Geological Society has elected the following officers for the coming year: president, ROY REYNOLDS, consulting geologist; vice-president, A. L. ACKERS, Stanolind Oil and Gas Company; secretary, R. D. SPRAGUE, Sinclair Prairie Oil Company.

A. LYNDON BELL, formerly with the Colombian Petroleum Company, may now be addressed at 26 Tanah Abang West Batavia-Centrum, Java, Dutch East Indies. Bell recently married and was accompanied by Mrs. Bell to Java.

James FitzGerald, Jr., of the Skelly Oil Company, was elected president of the West Texas Geological Society; M. B. Arick, of the Humble Oil and Refining Company, vice-president; and John M. Hills, of the Amerada Petroleum Corporation, secretary-treasurer.

E. C. Moncrief has resigned as chief geologist for the Derby Oil Company and will be associated with D. R. Lauck, Wichita producer, in Kansas operations. The firm will be known as Lauck and Moncrief.

James FitzGerald, Jr., formerly district geologist for the Skelly Oil Company in West Texas and New Mexico, is now the head of the district land department, with headquarters at Midland, Texas. Dana M. Secor, geologist in the Panhandle district, was transferred to Midland to replace FitzGerald as geologist. Willard F. Bailey succeeds Secor. W. C. Fritz will be production geologist for the West Texas-New Mexico division under Secor.

N. H. Darton, after nearly 51 years of Government service, most of which was spent with the United States Geological Survey, was retired on December 31 at the end of a year's presidential extension of the date. Being in fine condition, he plans to continue work on some unfinished reports, but will devote considerable time to private practice.

H. W. Haight, formerly of Monterrey, N. L., Mexico, has been transferred to Ebano, S. L. P., where he will be field superintendent for the Huasteca Petroleum Company.

Evan Just, formerly petroleum engineer with the Carter Oil Company, at Seminole, was appointed secretary of the Tri-State Zinc and Lead Ore Producers Association with headquarters at Miami, Oklahoma, effective January 1. He succeeds M. D. Harbaugh, who was elected vice-president of the Lake Superior Iron Ore Association with offices in Cleveland, Ohio.

L. R. Laudon, of the department of geology at the University of Tulsa, spoke before the Tulsa Geological Society, January 4, on "Researches of the Mississippian."

Leavitt Corning, Jr., read a paper, "Geology and Magnetics in Proven Fields," before the San Antonio Geological Society, San Antonio, Texas, December 21.

The Tennessee Division of Geology, Walter F. Pond, State geologist, is now established in its new quarters at 426 Sixth Avenue, North, Nashville. The offices are on the second floor of the new State Highway Building.

The Southern Louisiana Geological Society held its regular monthly meeting in the Majestic Hotel, Lake Charles, Louisiana, January 4, 1937. Following a luncheon, a regular business meeting was held. These officers for the coming year were elected: C. Ivan Alexander, Magnolia Petroleum Corporation, president; J. S. Kirkendall, Amerada Petroleum Corporation, vice-president; W. R. Canada, Stanolind Oil and Gas Company, secretary; and Baker Hoskins, Shell Petroleum Corporation, treasurer.

Robert S. Clark, microscopist with The Texas Company at the Kansas district office in Wichita for the past 2 years, resigned effective December 15 and is now associated with the consulting firm of Lerke and Whortan, 423

Union National Bank Building, Wichita, Kansas. F. E. METTNER of The Texas Company has been transferred from the Tulsa office to take the position of microscopist in the Wichita office.

The Wichita Micropaleontological Society met on November 31, at the Science Hall, Wichita University. Professor WALTER A. VER WIEBE was speaker of the evening. His address was "The Stratigraphy of the Wellington Formation."

RAYMOND C. MOORE, Kansas State geologist, spoke on "The Coal Measures of Europe," before the Kansas Geological Society at Wichita, November 18.

The Kansas Geological Society held its annual banquet and election of officers the evening of December 16 at the Allis Hotel, Wichita. The following officers were elected for the year 1937: president, J. I. DANIELS, Pryor and Lockhart; vice-president, A. E. CHEYNEY, Ohio Oil Company; secretary-treasurer, VIRGIL B. COLE, Gulf Oil Corporation; member of advisory board, THOMAS H. ALLAN, Twin Drilling Company.

E. S. SHAW presented a paper on "Oil Possibilities of Apache County, Arizona," before the Rocky Mountain Association of Petroleum Geologists, at Denver, Colorado, January 4.

The following officers of the Rocky Mountain Association of Petroleum Geologists have been elected for the coming year: president, H. W. OBORNE, Box 57, Colorado Springs; 1st vice-president, E. H. HUNT, Box 2100, The Texas Company, Denver; 2nd vice-president, W. O. THOMPSON, University of Colorado, Denver; secretary-treasurer, J. HARLAN JOHNSON, Box 336, Golden, Colorado.

The Tulsa Geological Society elected the following officers, January 4: president, FREDERIC A. BUSH, Sinclair Prairie Oil Company; 1st vice-president, ROBERT J. RIGGS, Stanolind Oil and Gas Company; 2nd vice-president, CHARLES G. CARLSON, Peerless Oil and Gas Company; secretary-treasurer, CLARK MILLISON, consulting geologist; editor, CLYDE G. STRACHAN, Gulf Oil Corporation.

V. R. D. KIRKHAM is the author of "Conservation and Stabilization Synonymous," published in the *California Oil World*, Vol. 29, No. 22 (December 17, 1936), pp. 6–9.

CHESTER W. WASHBURNE, consulting geologist, 149 Broadway, New York, is re-examining parts of Cuba.

The Southwestern Geological Society, the Bureau of Economic Geology, and the Department of Geology of the University of Texas, Austin, sponsored a field trip, February 13, including visits to near-by Tertiary and Cretaceous outcrops and to the older rocks of the Central Mineral Region. Following an informal dinner at the University Commons, PARKER D. TRASK of the United States Geological Survey spoke on "Source Beds of Petroleum."

After spending 3 months on vacation at his home in Denver, Colorado, LOUIS C. SASS has returned to Maracaibo, Venezuela, as assistant stratigrapher for the Venezuela Gulf Oil Company.

H. GORDON DAMON is president and H. B. STENZEL, of the University of Texas Bureau of Economic Geology, is secretary-treasurer of the Southwestern Geological Society, Austin, Texas.

The Panhandle Geological Society, Amarillo, Texas, has elected the following officers: president, JOHN E. GALLEY, Shell Petroleum Corporation; vice-president, G. L. KNIGHT, Phillips Petroleum Corporation; secretary-treasurer, C. C. HEMSELL, Columbian Fuel Corporation.

W. E. HEATER, of the Standard Oil Company of California, has recently returned from 3 years' duty in the Dutch East Indies. During the last year of his stay in that area he was doing geological work in New Guinea.

RICHARD C. KERR, formerly with the Continental Air Map Company, has become a member of the geological staff of the Standard Oil Company of California with headquarters at Bakersfield. The past summer Kerr was employed by the Inniskin Oil Company as a geologist during the operations of this company in Alaska.

W. F. JENKS spoke before the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, January 18, on the "Structure and Stratigraphy of the Belt Series North of the Coeur d'Alene District."

J. L. GREENFIELD, of the Seismograph Service Corporation, Tulsa, spoke on "The Applications of Seismograph work in West Texas," before the West Texas Geological Society, Midland, Texas, January 22.

The following officers were elected at the annual meeting of the Ardmore Geological Society: president, LINN M. FARISH, Sinclair-Prairie Oil Company, Ardmore; vice-president, EDWIN I. THOMPSON, Phillips Petroleum Company, Ardmore; secretary-treasurer, O. A. SEAGER, Carter Oil Company, Box 815, Wilson, Oklahoma.

The Shell Petroleum Corporation has opened a district office for East Texas area at 213½ South Broadway, Tyler, Texas (P. O. Box 2037). A. C. WRIGHT has been transferred from Shreveport as district geologist, C. L. HEROLD from Houston as assistant, and P. M. ROGGEVEEN from The Hague as stratigrapher.

STANLEY G. WISSLER, Union Oil Company of California, chairman of the program committee of the Division of Paleontology and Mineralogy, announces the following details for the half-day symposium on micropaleontology and stratigraphy of California mentioned on page 285 of this *Bulletin:* Cretaceous, PAUL P. GOUDKOFF, leader; Eocene, FRANK TOLMAN, leader; Oligocene and Miocene, leaders to be selected; Pliocene, H. L. DRIVER and W. F. BARBAT, leaders; Pleistocene, leader to be selected. In the case of the Miocene, all important oil-producing districts will be covered. In addition, an elaborate stratigraphic and faunal exhibit, including core samples and micro- and mega-fossils, is being arranged for the Los Angeles and the San Joaquin Valley regions.

OKLAHOMA

ELFRED BECK
Geologist

614 National Bank of Tulsa Building
TULSA OKLAHOMA

W. V. HOWARD
Geologist
J. G. WRAY & CO.
Operation—Appraisal

615 Wright Bldg. TULSA
3324 Bankers Bldg. CHICAGO

R. W. Laughlin L. D. Simmons

WELL ELEVATIONS
Oklahoma, Kansas, Texas, and New Mexico

LAUGHLIN-SIMMONS & CO.
605 Oklahoma Gas Building
TULSA OKLAHOMA

G. H. WESTBY

Geologist and Geophysicist

Seismograph Service Corporation

Kennedy Building Tulsa, Oklahoma

TEXAS

E. DEGOLYER
Geologist
Esperson Building
Houston, Texas
Continental Building
Dallas, Texas

DAVID DONOGHUE
Consulting Geologist

Appraisals - Evidence - Statistics

Fort Worth National Bank Building
FORT WORTH, TEXAS

GINTER LABORATORY

CORE ANALYSES
Permeability
Porosity
Reserves

R. L. GINTER
Owner

118 West Cameron, Tulsa

MID-CONTINENT TORSION BALANCE SURVEYS
INTERPRETATIONS

KLAUS EXPLORATION COMPANY
H. KLAUS
Geologist and Geophysicist

404 Broadway Tower Enid, Oklahoma

GEO. C. MATSON

Geologist

Philcade Building TULSA, OKLA.

TEXAS

D'ARCY M. CASHIN
Geologist *Engineer*

Specialist, Gulf Coast Salt Domes

Examinations, Reports, Appraisals
Estimates of Reserves

705 Nat'l. Standard Bldg.
HOUSTON, TEXAS

ALEXANDER DEUSSEN
Consulting Geologist

Specialist, Gulf Coast Salt Domes

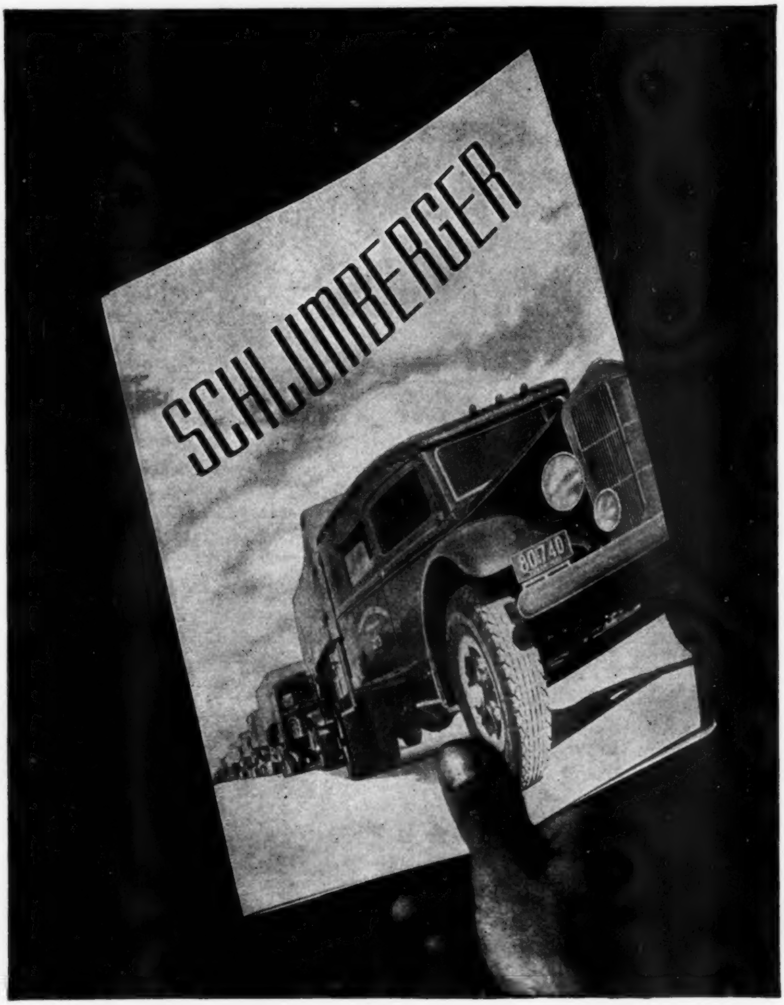
1606 Shell Building
HOUSTON, TEXAS

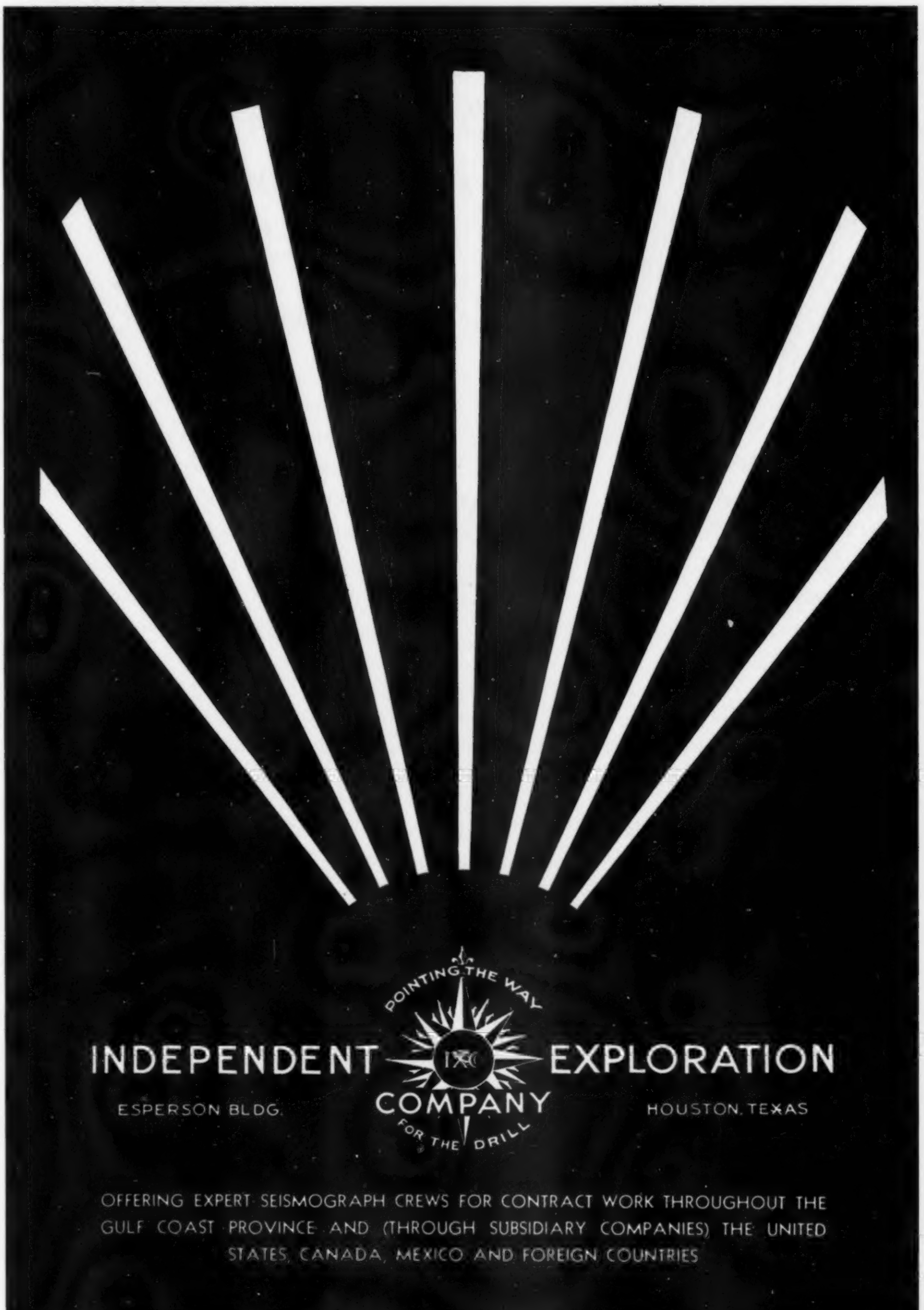
F. B. Porter
President

R. H. Fash
Vice-President

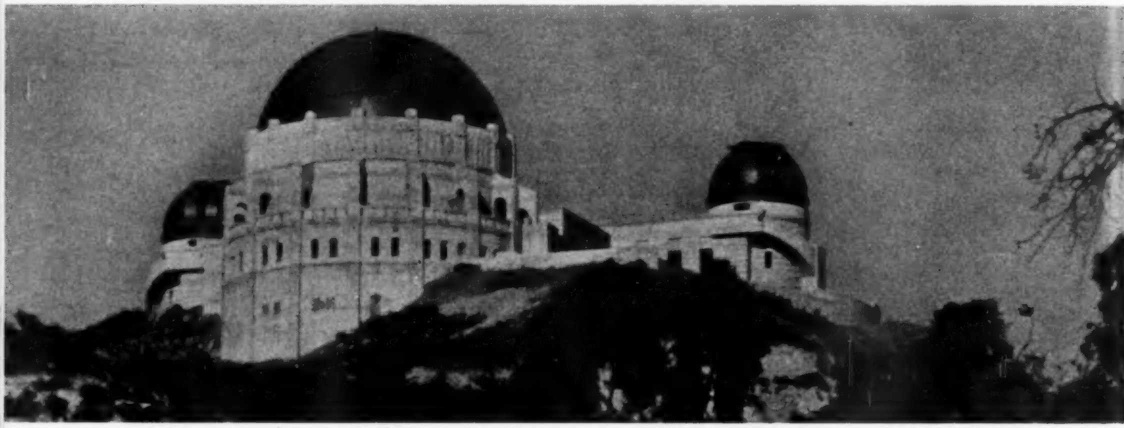
THE FORT WORTH LABORATORIES

Analyses of Brines, Gas, Minerals, Oil. Interpretation of Water Analyses. Field Gas Testing.
828½ Monroe Street FORT WORTH, TEXAS
Long Distance 138


SCHLUMBERGER


POINTING THE WAY
INDEPENDENT EXPLORATION
COMPANY
FOR THE DRILL
ESPERSON BLDG.
HOUSTON, TEXAS
OFFERING EXPERT SEISMOGRAPH CREWS FOR CONTRACT WORK THROUGHOUT THE GULF COAST PROVINCE AND (THROUGH SUBSIDIARY COMPANIES) THE UNITED STATES, CANADA, MEXICO AND FOREIGN COUNTRIES

ORANGE GROVES WITH SNOW-COVERED MOUNTAINS IN BACKGROUND, LOS ANGELES COUNTY



PLANETARIUM, GRIFFITH PARK, LOS ANGELES

ON THE BEACH, LOS ANGELES COUNTY